WIRELESS

ITS PRINCIPLES
AND PRACTICE

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BY

ROBERT WILLIAM HUTCHINSON, M.Sc.

Author of "Advanced Textbook of Electricity and Magnetism"
"Intermediate Electricity," "Elementary Electricity and Magnetism
"Easy Lessons in Wireless," "Television Up-to-Date," etc.
Joint Author of "Technical Electricity," etc.

Formerly Revising Examiner in Electricity and Electrical
Engineering, Union of Educational Institutions

Late Principal, Municipal Technical College, Smethwick

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PREFACE TO THE FIRST EDITION

NUMEROUS requests, over an extended period, have been received by the publishers and myself for a revised edition of my *First Course in Wireless* which was published in 1926 and which met with such an amazing success. It was felt, however, that in view of the great advances which "Wireless" has made since that date, a revision, as usually understood, would not meet the case—it would neither do justice to the subject nor meet the requirements of the readers of to-day. It was therefore decided to deal logically with the subject in its present aspect and to write and produce a new book. But in doing this I have followed the same method of treatment as I did with the previous work—a treatment which a long experience showed me to be essential—a treatment which met with the wholehearted approval of the Press, and has been thoroughly appreciated by teachers, students, wireless experimenters, and the wireless public.

The object of *Wireless: Its Principles and Practice* is to give the reader a clear insight into the fundamentals of wireless and its practical working *to-day*, and to base his knowledge from the outset on sound scientific principles. To this end no previous knowledge of electricity or of "radio" is assumed, and a brief but sufficient account of all the necessary theory and modern views is given in a simple, rational, and scientific way which will neither conflict with the ideas of the physicist nor result in the practical student and general reader having to abandon their conceptions as their reading takes them into higher stages. This theory is associated with its wireless applications from the outset so that the reader will see exactly the necessity for it; it is made simple and interesting so that he will have no difficulty in understanding it. And further ahead in the book when he is dealing with the actual circuits of to-day and the technical applications of

the subject he will encounter no term, expression, or explanation which he cannot understand.

The book is intended for beginners, for wireless amateurs and experimenters, for the members of Radio Clubs and Societies, for students in Evening Continuation and Technical Classes, etc., for the wireless public, for that ever increasing body of men and women who are not satisfied with merely " listening in " but who are inquisitive as to the why and the wherefore of things and who take an intelligent interest in their receivers and their reception. And although Mathematics and Mathematical Physics have been purposely avoided, it is hoped that the book may prove of interest and of some service even to the more advanced student who already possesses a knowledge of Electricity and Electrical Engineering—as an introduction, for example, for the student about to begin the detailed wireless courses at our Technical Institutes.

My point of view is that of one who has had many years teaching experience with students of all ages in Day Schools, Technical Institutes and University Classes, close association with Wireless Societies, and over twenty-five years' experience with experimental wireless. This will explain why certain portions are treated at comparatively great length and certain portions particularly emphasised and even repeated, and why simple theory runs hand in hand with the practical " wireless " applications throughout the book. This same experience has shown me that the conception of potential, the visualisation of the electronic current, etc., the twisting round of old ideas to fit the new, can be appreciated even by young beginners if the matters are dealt with in a homely way, and this I have tried to do.

Where, for the sake of clearness in explanation or to acquaint the reader with general appearances, I have taken actual examples of appliances, I have endeavoured to select representative types, giving at the same time the scientific principles underlying their construction and action. In a few cases I have tendered some advice based on experience: in a book of this type intended for beginners,

and with a subject like wireless in which thousands of all trades, businesses, and professions are interested, any extra help is an error in the right direction if an error at all.

R. W. HUTCHINSON.

NOTE TO THE SECOND EDITION

THE demand for a further issue of this book—first published in December of last year—combined with the favourable views expressed alike by readers and the Press, indicate that my aim, as outlined in the Preface to the First Edition, has met with approval, and I have taken the opportunity thus afforded to incorporate some details of the developments which have taken place since the beginning of the present year.

And so far, 1933 has been a period of rather bewildering advances in the domain of Wireless. Early in the year rumours began to circulate that a new form of low-frequency amplification—a modification of the well-known "push-pull"—was about to be introduced, and this soon appeared in the form of "quiescent push-pull" (Q.P.P.), its aim being to produce a much greater volume output with comparatively small battery consumption and therefore reduced running and renewal costs. But Q.P.P. had the field *to itself* for a very limited period, for right on its heels came another method of attaining the same object—a method now known as Class B amplification—rendered possible by the advent of the Class B valve. Transformer and other component manufacturers who had just designed special apparatus for Q.P.P. had therefore to begin again and place on the market modifications to comply with Class B requirements. Concurrently with this, research was going on in other directions. Automatic volume control (A.V.C.)—the levelling-up (or cutting down) by the receiver itself of signal strength—the elimination of fading on distant stations and of blasting on strong locals—was receiving attention, and new valves appeared to cope

with the process. Meanwhile all-metal valves, cold valves, various multi-purpose valves, iron-dust-core tuning coils and valve couplings, and new loud speaker and eliminator components were appearing—all to fit in with new advances being made in the completed circuit designs of to-day.

For the present edition I have therefore endeavoured to deal with most of the leading points in a simple manner suitable for the beginner. Matter has been added on the new-comers in the domain of valves—Class B, double-diode-triodes, double-diode-pentodes, high-frequency pentodes, short-base variable-mus, catkins, Westectors, hexodes, pentagrids—on push-pull, quiescent push-pull, and Class B amplifications, on automatic volume control, mains units, loud speaker baffles, and iron-dust-core coils, while additional modern circuits have also been included.

R. W. HUTCHINSON.

NOTE TO THE FOURTH EDITION

THE continued and somewhat rapid demands for further issues of this book have enabled me to endeavour to keep the work up to date, so far, at least, as the scope and aims of the book permit. For the third edition the sections on television were extended by the inclusion of matter dealing briefly with high definition. For the present edition some sections have been further simplified, some have been extended, and new matter has been incorporated dealing with short wave work, "short-wave," "all-wave" and "noise-eliminating" aerials, directional transmission, wireless direction-finding for navigational purposes, and television. Several new diagrams have been included.

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R. W. HUTCHINSON.

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WIRELESS:
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CHAPTER I.

A FEW NECESSARY IDEAS ABOUT ELECTRICITY AND MAGNETISM.

1. The Atom, the Proton, and the Electron.

The name *substance* or *material* or **matter** is constantly used in everyday life, but it is not altogether easy to explain exactly what "matter" is. The scientist certainly gives us a definition; he may tell us that matter is "that which occupies space," but this seems rather vague to a beginner. For our purpose, however, we will take it that matter is all the different kinds of stuffs that we can see, feel, weigh, etc. Some are solids, some are liquids, and some are gases.

Now in order to understand many facts in modern science—indeed to understand such modern everyday conveniences as the electric light, electric trains and trams, telegraphy, telephony, wireless, television, tele-talkies, and tele-photography—it is necessary to have some idea as to how matter is made up, and in order to drive the idea home to the reader with little or no scientific training or knowledge we must do a fair amount of "imagining." In explaining what were, at the time, some new ideas in science, Professor Clerke-Maxwell used to imagine a tiny being, a "little demon" with the same faculties as ourselves (but considerably sharper) who was able to see things infinitely smaller than we can see, and do things infinitely smaller than we can do. We will, in this first Chapter, sometimes adopt a somewhat similar plan: but our readers

with some knowledge of electricity will realise that in doing this we are merely trying to make new and important ideas clear to the *beginner*.

We know from ordinary experience that every piece of matter can be divided into smaller pieces by suitable means. We can split up a large sheet of glass into very tiny pieces, and we can go on pounding the tiny pieces until we get a fine glass powder. If we drop a crystal of permanganate of potash into a glass of water the crystal will dissolve, *i.e.* break up into small particles which spread right throughout and colour the whole liquid. If a small quantity of musk is brought into a room it " scents " the whole room, showing that the musk has split up into a very large number of small particles. All the above and many other experiments prove that matter is very *divisible*.

Now suppose you take a piece of an " elementary " substance—an *element* as the chemist calls it—say copper, and cut it into smaller and smaller pieces until you cannot cut it any more. Suppose, however, that you now slowly become the " little demon "—with suitable shears. You will then be able to go on cutting the copper millions and millions of times, until finally you will reach the state where it really cannot be divided any further. You would then have in front of you the so-called ultimate and indivisible part of which all copper is made up. This is called an **atom** of copper.

Incidentally, to be exact, the smallest particle of a substance which can exist free, *i.e.* lead a separate existence, is called a **molecule,** but a molecule is made up of atoms and in the case of metals like copper the molecule really contains only one atom: but this is a detail we need not consider here.

Of course the chemist gives us a very exact definition of the atom: he says " an atom is the smallest part of an element which can take part in a chemical change, *i.e.* can enter or leave a chemical compound "—but we will also leave that at that for the present.

All atoms are excessively small—it would take of the order a hundred million side by side to make an inch—and

we can never hope to divide down to them, or see them directly even with far more powerful microscopes than we have at present.

Now if all this imagining were real and you—the little demon—were looking into the atom of copper, what an extraordinary sight you would witness. You would find that it consisted of a nucleus—a ball at the centre—surrounded by a number of small particles in very rapid motion and revolving round it. You would notice what a large distance compared with their own size many of the revolving particles were from the nucleus, and you would also notice how very much bigger the nucleus was than the revolving particles: the difference in size, in fact, between the nucleus and a particle would be similar to that between St. Paul's Cathedral and one of the pigeons in its vicinity.

The whole atom would rather—only *rather*—resemble our solar system with its central sun and the revolving planets.

The nucleus of the atom is mainly composed of what we call **positive electricity** due to particles in it known as **protons,** and the much smaller particles are what we call **negative electricity** or **electrons**: the total (free) positive electricity at the nucleus is equal to the total negative electricity, of all the electrons added together.

Electrons have actually been detached from all sorts of matter and carefully investigated, and in all cases they are identical. They are the lightest "things" known, their mass (which is probably purely electricity) being always about $\frac{1}{2000}$ of the mass of a hydrogen atom, which is the lightest atom known, and each always shows the same amount of electricity: we cannot get a smaller charge of electricity. The proton positive charge equals the electron negative charge, but the proton's mass is much the greater: it is about equal to the mass of a hydrogen atom.

Moreover, these electrons are inconceivably small. It would take nearly sixteen million times a million of them in a row touching each other, to make an inch. Thus the atom is certainly very tiny, but it is of the order a thousand million million times the very tiny electron: a circular field about two and a half miles in diameter with

a golf ball in it will give some idea of the relative size of the atom and the electron.

Now every substance that we know has its atom made up in the same way as the atom of copper, considered above, *i.e.* in all cases the atom consists of a centre or nucleus of positive electricity surrounded by moving particles of negative electricity or electrons, and it is merely the number and arrangement of the electrons in the atom which determine its properties—determine in fact what the substance really is. Thus a system of one kind gives us what we call zinc, a system of another kind gives us copper, a system of another kind gives us silver, and so on.

In books on Chemistry there is usually a table—the Periodic Table—of all the known elements arranged in the order of increasing weight of atom. As a further illustration, if we take the names as given in this table, an atom of hydrogen consists of one revolving negative electron outside the nucleus and a nucleus having, on the whole, an equal free positive charge, an atom of helium has two electrons outside the nucleus, and the latter has two equal free positive charges, lithium has three electrons and a nucleus with three equal free positive charges, beryllium has four, boron five, carbon six, nitrogen seven, oxygen eight, and so on up to uranium with ninety-two.

But the marvellous thing to bear in mind just now is that when we get to rock-bottom, the atoms of all these elements merely consist of a nucleus of positive electricity (protons), and a number of rapidly moving particles of negative electricity or electrons. Of course, most of the substances we encounter in daily life are not elements and are not listed in the chemist's periodic table: they are, however, built up of various elements, so that when we get down to the fundamentals of all materials we have the protons and very tiny electrons as indicated above.

And it is this structure within the atom which endows matter with all its electrical and chemical properties; it is due to these electrons and protons that we have such

modern conveniences as electric light, electric trains, telegraphy, wireless, television, and so on.

In addition to protons there are electrons in a nucleus, but there are more protons than electrons there, so the nucleus is *on the whole* positive. (An electron *in a nucleus* is joined with a proton forming a **neutron** with no charge since the electron (—ve) and the proton (+ve) neutralise.)

2. Positive and Negative Charges of Electricity.

The ancients knew that pieces of amber possessed, when rubbed, the property of attracting light bodies, and it is from the Greek name **ēlektron** (amber) that our word " electricity " is derived.

It is now well known that, with proper precautions, all substances, suitably rubbed, will attract to some extent such light articles as pieces of paper, bran, cork, pith, etc.: glass rubbed with silk, sealing-wax with flannel, and vulcanite with fur, do so in a marked degree. A substance endowed with this property is said *to be electrified*, *to be excited*, *to be charged*, *to possess a charge*, or *to be in a state of electrification*, and the agent which is the cause of this state is named **electricity.** Bodies not endowed with the property mentioned are said to be electrically *neutral.*

Now if you rub a vulcanite rod with fur and suspend it by a dry silk thread from a suitable stand (we say silk because silk does not allow any electricity to escape along it: it is an *insulator*: a *conductor* allows electricity to flow along it—see later) and then bring near it another vulcanite rod which has also been rubbed with fur, the suspended one will be repelled: but if you bring near it a glass rod which has been rubbed with silk the suspended rod will be attracted. Similarly if the electrified glass be suspended, a second glass rod excited with silk will repel it, but the vulcanite rod rubbed with fur will produce attraction.

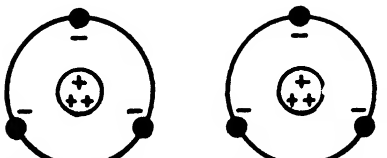
Numerous early experiments like the above with various substances led to the conclusions (1) that there were two states of electrification, (2) that bodies in similar states of electrification repelled each other, (3) that bodies in unlike states of electrification attracted each other.

It was agreed in those early days to call the state of electrification of glass rubbed with silk, **positive**, and to say that the glass was "*positively*" *charged*; it was further agreed to name the state of electrification of vulcanite rubbed with fur **negative**, and to say that the vulcanite was "*negatively*" *charged*. Hence we have the important laws: (1) Positively-charged bodies repel each other. (2) Negatively-charged bodies repel each other. (3) A positively-charged body and a negatively-charged one attract each other.

So far we have not bothered about the rubber, but it can be shown that when vulcanite is rubbed with fur, not only is the vulcanite negatively charged, but at the same time the fur is positively charged and by an equal amount. Similarly with the glass—the glass is positively charged and the silk is, at the same time, negatively charged and by an equal amount.

These names were decided on long before electrons, etc., were discovered. When electrons were discovered it was found that they acted just like the vulcanite above and therefore were "negative." It would have made things to-day a little less confusing if the early physicists had decided to call the glass negative and the vulcanite positive. You will see this presently.

Now let us get back to our atoms—our protons and electrons—and see if we can get an explanation of the preceding. Remember this: If we remove electrons from the atoms of a substance we may change the properties of the substance altogether and produce what is known to us as quite a different substance. On the other hand, the removal of electrons (or the addition of electrons) may simply produce electrification. The latter is the case which concerns us at present.

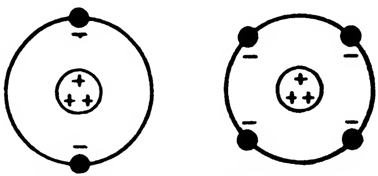


Neutral Atom. Neutral Atom.

Fig. 1.

In Fig. 1 are shown two atoms, each consisting of a positive nucleus carrying a treble charge and three electrons. In this case the attractions and repulsions between the atoms balance, *i.e.* the atoms as a whole neither attract nor repel each other: they are neutral.

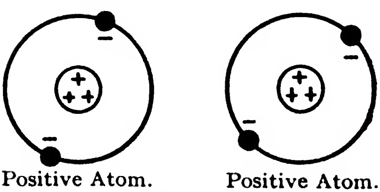
In Fig. 2 one of the electrons has been detached from one atom and absorbed by the other, so that the first atom is positively charged, since the positive nucleus predominates, and the second atom is negatively charged, since the negative electrons predominate. The positive portion of the first atom tries to recapture the electron it has lost and to which it is entitled (or to get hold of another one in place of it), and the electron is equally anxious to get back: thus the attraction between the two oppositely charged atoms is due to the attraction between the extra positive nucleus charge in one and the surplus electron in the other.



Positive Atom. Negative Atom.

Fig. 2.

An atom which has lost an electron is usually spoken of as a **positive ion**, and one which has gained an electron as a **negative ion**. The force between a positive ion and an electron is enormous, almost beyond our comprehension: if gravity were as great, a man would weigh hundreds of tons.



Positive Atom. Positive Atom.

Fig. 3.

In Fig. 3 we have two atoms which have each lost an electron, so that both are positively charged. In this case the repulsions between the atoms overbalance the attractions, and the result is repulsion. A similar result follows in the case of two atoms which contain an extra electron each, and are, therefore, negatively charged.

When vulcanite is rubbed with fur some electrons pass from the fur atoms to the vulcanite atoms. The vulcanite has a surplus of electrons, and is negatively charged: the fur has a deficit of electrons so that the positive centres predominate and the fur is positive. When glass is rubbed with silk, electrons pass from the glass to the silk so that the glass is positive and the silk negative. Note that it is *electrons which move* from atom to atom; the nucleus is more or less fixed in the atom.

3. Electric Field. Electric Lines of Force.

We have seen that an electrified body attracts light bodies and attracts or repels other electrified bodies. Now the space surrounding an electrified body within which the influence of the electrified body extends is called an **electric field.** If a small positive charge absolutely free to move were placed at any point in such a field, it would be urged by a definite force in a definite direction and that direction can be indicated by what is called a **line of electric force** passing through the point in question.

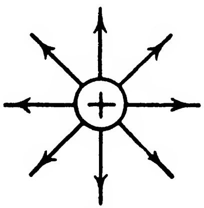


Fig. 4.

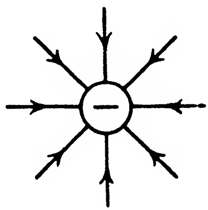


Fig. 5.

Fig. 4 shows some of the lines of force in the case of a positively-charged ball in the centre of a large room. A *very tiny positive charge,* free to move, would be repelled straight away from the ball in the direction of these lines. Fig. 5 shows the case for a negatively-charged ball: the tiny positive charge would be attracted up to the ball in the direction of these lines. The direction of an electric field or of a line of force, or the positive direction as it is sometimes called, is the direction in which a free positive

charge moves: the arrows show the positive direction of the lines in Figs. 4 and 5.

Fig. 6 shows the lines of electric force in the case of two metal balls with equal charges, the one positive and the other negative, and Fig. 7 shows the lines in the case of two equal positive charges placed at points a short distance apart. It should be noticed that in the latter case the lines from the two like charges turn away from each other, but in the former case the lines pass from one body to the other.

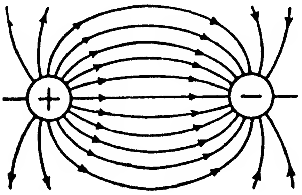


Fig. 6.

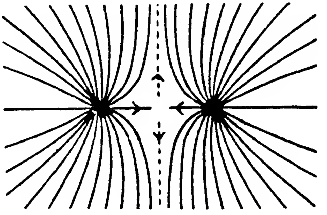


Fig. 7.

In order to explain attraction between unlike charges and repulsion between like charges Faraday imagined these lines of electric force to be, so to speak, real connections between the charges, and further he imagined that each line tended to shorten in the direction of its length, whilst lines proceeding in the same direction tended to repel each other laterally, *i.e.* sideways.

Clearly this contraction in the direction of their length will account for the attraction between unlike charges (examine Fig. 6), for this will tend to pull them together, and repulsion sideways will give an explanation of the repulsion between like charges (examine Fig. 7), for this will tend to move them apart.

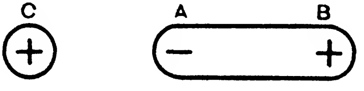


Fig. 8.

Let C, in Fig. 8, be a positively-charged body and AB a metal body which, when it was not near C, did not show

any signs of electrification (*i.e.* it was *neutral*). When it is placed, as shown, the end A becomes negatively charged and the end B positively charged. The positively-charged body C attracts some of the electrons of AB towards the end A, so that this end has a surplus of electrons and is negatively charged, whilst the other end B has a deficit of electrons and is positively charged.

These effects, taking place across the space between C and AB, are referred to as *electrostatic-induction*. Fig 9 shows the electric lines in this case. Notice that many of the lines starting from C end at the negative charge on AB: the other lines from C really end at a negative charge which is induced on the walls, etc., of the room. So in Fig. 4; the lines from the positive charge on the ball end at an equal negative charge induced on the walls, etc., of the room.

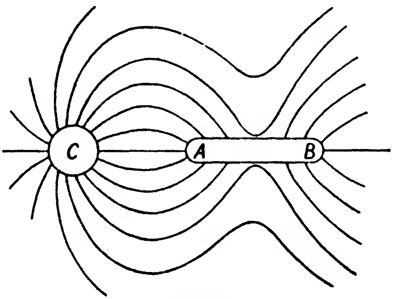


Fig. 9.

Suppose you have a light pith ball suspended at the end of a silk thread and, holding the thread in the hand, you bring the pith ball gradually near a strongly electrified body: when you get to within a certain distance of the latter the pith ball is attracted towards it. Now hold a large sheet of metal—say copper—in between the pith ball and the charged body: the pith ball is no longer attracted. The sheet of copper (which is really *joined to earth* by your hand and body) acts as a **screen** protecting or screening the pith ball from the influence of the electrified body. The lines of force from the charged body end, in fact, on the earth-connected plate and do not pass through into the space beyond where the pith ball is. The same idea is shown in Fig. 10*a*. Here the positively-charged body A is inside a metal enclosure, and we have a negative charge

induced on the inside and a positive one on the outside: when the enclosure is earthed (Fig. 10*b*), the outside charge and the lines outside disappear so that anything outside is now protected or screened from the influence of A. Metal plates and cans are largely used in this way as "screens" in wireless receivers.

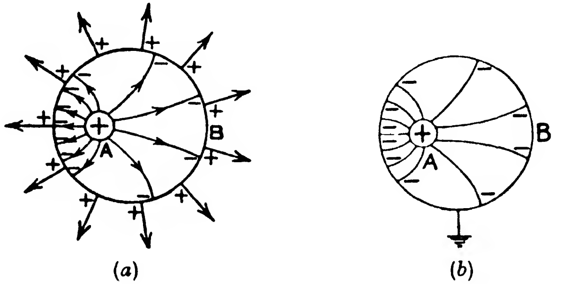


Fig. 10.

4. The Electric Current: Resistance.

In these days most people know that the expression "electric current" means a flow of electricity—frequently along a metal wire—and most people know something about a "battery," which is one of the many devices for producing an electric current.

The action of a battery, as will be seen later, is simply this; it causes an excess of electrons to be piled up at what is called the "negative pole" of the battery, and at the "positive pole" of the battery an excess of positive ions, *i.e.* atoms which have lost an electron: further, what is termed a "difference in electrical pressure" is set up between the poles, and as soon as a road is made between these poles by joining them with, say, a copper wire, this difference in electrical pressure drives electricity along the wire. All this will be understood later.

Suppose then a copper wire with its end A joined to the positive pole of the battery and its end B joined to the negative pole. To fix ideas we will do a little more "imagining." Imagine that, before the wire is joined up

as above, you have once more become the "little demon" and that you are just up against the surface of the wire having a peep inside. You would, of course, see a large number of atoms each with its positive nucleus and its revolving electrons.

Now suppose someone joins up and "starts the current." You would immediately see a huge army of electrons—millions of them in fact—coming from the direction of B towards the direction of A, going in between the atoms and through the atoms, colliding with each other and with the electrons in the atoms, driving some of the latter out and taking their place.

This hurrying, scurrying, bumping movement of electrons in the general direction B and A of the copper wire, *i.e.* from the negative pole to the positive pole of the battery, is the **electric current,** and the greater the number of electrons passing per second the greater is said to be the **strength of the current.** We will call this the **electronic current** for a reason which will be seen presently.

Now let us get back and examine the process a little more in detail. Let us, for example, concentrate our attention on one of the free electrons at the negative pole of the battery. This electron rushes into an atom at the end B of the wire, and it does so with such force that it drives out one of the atom's own electrons and takes its place. This evicted electron dives into the next atom, driving out an electron and taking its place. And so this goes on from atom to atom all along the wire, until finally at A an evicted electron is taken in by a positive ion waiting, as it were, for it. As to what happens next, you need not trouble at present—that is the story of how a battery works.

Of course, in practice, it is not a matter of one electron entering the end B and another leaving the end A of the wire, but millions upon millions per second, and, of course, considerable bumping.

Again, all this knocking, this bumping, this wrenching-out of the electrons in the atoms, means that the current is encountering a certain difficulty in, a certain opposition

to, its flow; this is spoken of as the **resistance** of the electric circuit. Clearly *the less the resistance the greater will be the current strength.*

Now just as we measure distances in terms of a certain unit—the yard, the foot, etc., and mass in terms of a certain unit—the pound, the ounce, etc., so we measure current strength in terms of a certain unit of current strength, and resistance in terms of a certain unit of resistance. The unit of current strength is called the *ampere* and the unit of resistance is called the *ohm.* These are dealt with in the next chapter; for the present, however, you should merely remember that we speak of *a current strength of so many amperes* and of *a resistance of so many ohms.*

5. Electric Potential or Electric Pressure.

One of the most important ideas in the study of electricity is what is known as **electrical potential** or **electrical pressure,** and it is essential that you should try to grasp the idea. It will help towards this end if you first consider the following analogies, bearing in mind, however, that though the analogies are helpful, they are rather faulty in detail and must not be pushed too far.

It is well known that heat flows from a body at a high temperature to a body at a low temperature. If two bodies be connected together by a conductor of heat, and no heat passes from one to the other, the two bodies are at the same temperature; if the two bodies are at different temperatures, then heat will flow from the one at the higher temperature to the one at the lower temperature, and this flow will continue until the two come to the same temperature.

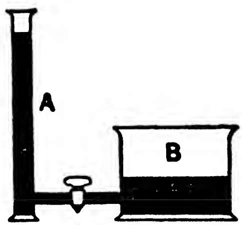


Fig. 11.

It is also well known that water flows from a high water level to a low water level. Thus, if the two vessels of Fig. 11 contain water as indicated, then on opening the stop-cock

water will flow from A to B, and the flow will continue until the two come to the same level. The actual quantity of water in B may be considerably greater than the quantity in A; *it is the difference in level which settles the direction in which the water will flow.*

Again, consider an air-tight box fitted with a stop-cock and pressure-gauge. Pump air into the box and then close the stop-cock. The gauge will indicate that the air pressure inside is greater than that outside. Open the stop-cock; *air will pass from the box into the atmosphere,* i.e. from the region of higher pressure to that of lower pressure, and this will continue until the gauge indicates that the air pressures inside and outside are the same. Now draw air out of the box, and then close the stop-cock. The gauge will indicate that the air pressure inside is less than that outside. Open the stop-cock; *air will then pass from the atmosphere into the box,* i.e. from the higher pressure to the lower pressure, and this will continue until the gauge indicates that the air pressures inside and outside are the same.

Further, in measuring temperatures by a Centigrade thermometer, the temperature of melting ice is taken as the standard of reference or the zero. Similarly, in measuring heights of mountains, etc., the sea-level is taken as the zero level.

In the study of electricity *electrical pressure* or *electrical potential* has much the same meaning as temperature, level, and pressure in the above cases. Now, as we have already casually mentioned, in the early days the pioneers in electricity did not know about electrons and protons and the inside of an atom, and so the names they invented and the ideas they put forward to explain things are sometimes not altogether in harmony with recently discovered facts. The names, however, are still in use, and a certain amount of "twisting round" so to speak is necessary to make them fit in with modern ideas. This is rather confusing to a beginner, but the difficulty disappears later. One of these difficulties is cropping up now.

Consider a positively-charged brass ball hanging by a silk thread. We know that this has got a deficit of

electrons. Now if this ball be joined to the earth by a wire, we find it becomes neutral and we know the cause—electrons must have come up from the earth to make up the deficit, i.e. *an electronic current has passed from the earth to the ball.*

But the early pioneers did not know about these electrons, and they reasoned in this way. The positive ball, they said, has a surplus of electricity: when joined to earth this surplus electricity flows to earth, and it does so because the electrical pressure (or potential) of the ball is higher than the electrical pressure (or potential) of the earth. *The electric current*, they said, *flowed from the higher potential ball to the lower potential earth.* Further, the earth was taken as the zero of potential, and the ball was said to be at a positive potential.

As this latter current is still frequently spoken of we call it the **conventional current** to distinguish it from the true electronic current which flows the other way.

Again, if a negatively-charged ball, *i.e.* one with a surplus of electrons, be joined to the earth it also becomes neutral, and we know that this must be due to the surplus electrons passing to earth, *i.e. an electronic current has passed from the ball to the earth.*

But the early pioneers said this: The negative ball has a deficit of electricity: when joined to earth electricity flows from the earth to make up the deficit, and it does so because the electrical pressure (or potential) of the ball is lower than the electrical pressure (or potential) of the earth. *The electric current*, they said, *flowed from the higher potential earth to the lower potential ball*, and as the earth is taken as zero potential, the ball was said to be at a negative potential: this current we must also call the conventional current to distinguish it from the true electronic current which flows the other way.

To summarise, then, we may say: The potential of a body is its electrical pressure above or below that of the earth which is taken as the standard or zero: it is the electrical condition which settles the direction in which an electric current will flow. *A body* A *is at a higher potential*

or electrical pressure than a body B *if a conventional current tends to flow from* A *to* B, *and of course a true electronic current from* B *to* A, *and* A *and* B *are at the same potential if electricity does not tend to flow between them.*

Potential difference (P.D.) or electrical pressure difference is therefore necessary in order to get a flow of electricity, *i.e.* a current, and if we want to keep up the current we must keep up the potential difference.

The positive pole of a battery is at a higher potential than the negative pole, and when joined by a wire this potential difference or pressure difference drives a current through the wire. The current is really a movement of electrons—the electronic current—from the negative pole to the positive pole, but we still frequently speak of the current as flowing from the positive pole to the negative pole, *i.e.* we speak of the conventional current.

Electrical potential or pressure is measured in units called *volts*, *i.e.* we speak of *an electrical pressure of so many volts.* Clearly *the bigger the pressure or voltage between two points the bigger will be the strength of the current it drives between the two points.*

There is just another point which you must notice, and that is that when we electrify a body we do not *make* electricity. Further, dynamos are used in running factories, huge electric machines are used in power stations for heating and lighting and traction, magnetos are used on motor cars and motor cycles, batteries are used for electric bells, etc., but none of these generators, as they are called, *make* electricity: they no more manufacture electricity than a pump manufactures water. Electricity is in everything, all matter is really composed of it, and dynamos, batteries, etc., are merely pumps which give " head " or " pressure " to the electricity and make it able to do something it could not do before.

6. Magnetism, Magnetic Field, Magnetic Lines of Force.

Most people know what a magnet is: it is a piece of iron or steel (generally horse-shoe shaped or in the form of a bar) which attracts other pieces of iron and steel, and which,

if suspended, comes to rest in a definite direction which is nearly north and south, the one end always pointing towards the north and the other end towards the south. The end which points towards the north is called the *north pole* of the magnet and the end which points towards the south is called the *south pole* of the magnet.

Incidentally, *permanent* magnets are made of very hard steel, but what are called *electromagnets*, which are used in several electrical appliances, and which are required to quickly become magnetised and to quickly lose their magnetic properties, are made of soft iron. Further, only iron and steel can be made to show magnetic properties to *any marked degree*, and they are spoken of as *magnetic substances*. Nickel, cobalt, and manganese can show magnetic properties but they are very weak compared with iron and steel.

Now if the north pole of a second magnet be brought near the north pole of a suspended magnet there will be repulsion between them, but if the north pole be brought near the south pole of the suspended magnet there will be attraction. Similarly two south poles repel each other. Thus we have the important law that "Like poles repel each other and unlike poles attract each other."

The space outside a magnet throughout which its influence is felt is called the **magnetic field** of the magnet. Now we cannot get a north pole by itself or a south pole by itself as we can get positive and negative charges by themselves, for a (perfect) magnet always has two poles, one north the other south. Let us imagine, however, that we have got a single north pole. If this north pole be placed at any point in a magnetic field it will be urged by a definite force in a definite direction, and this direction is indicated by what is called a **line of magnetic force** passing through the point in question. *The* direction of the field or line

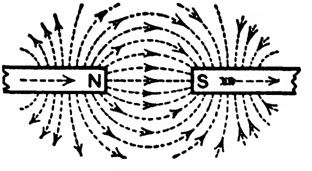


Fig. 12.

of force, or the positive direction, is the direction in which the free north pole moves.

Fig. 12 shows the lines of magnetic force in the case of two unlike poles facing each other, and Fig. 13 shows the lines in the case of two like poles. You can easily show the direction of these lines by placing the magnets under a sheet of cardboard and sprinkling iron filings out of a muslin bag on to the cardboard: the filings will arrange themselves along the lines of magnetic force.

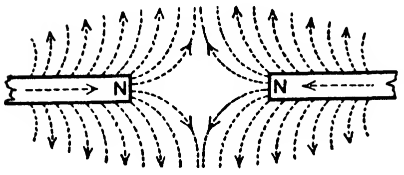


Fig. 13.

Suppose AB (Fig. 14) is a bar magnet lying on the table, the end B being the north pole. Now place a piece of soft iron CD in the position shown. It will be found that CD becomes a magnet, the end C nearest the north pole of AB being a south pole. If the magnet pole nearest the end C of the iron had been a south pole then C would have been a north pole. These effects taking place across the space between AB and CB are referred to as *magnetic induction*, and CD is said to be magnetised by induction. All this resembles to a certain extent the electrostatic induction referred to in Art. 3.

Fig. 14.

Now there is a very important connection between electricity and magnetism, and that is that *whenever an electric current flows along a wire a magnetic field is set up on all sides of it, the lines of magnetic force forming circles round about the wire,* and when the current stops the magnetic field disappears.

You can show that there is a magnetic field outside the wire by holding the wire in a north and south direction

above a small pivoted magnet (watch-chain compass): the compass will be deflected (Fig. 15). If the north pole of the compass moves, say, to the right when the current is going one way, it will move to the left if the current flows in the opposite direction. Further, if you pass the wire vertically through a hole in a sheet of cardboard (Fig. 16), you can show the circular lines of force by means of iron filings.

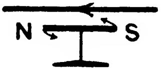


Fig. 15.

The compass needle mentioned above gives you a ready method of finding which way a current is flowing in a wire. Set the compass down on the table, say, and of course it will come to rest pointing north and south, its north pole pointing northwards: hold the wire carrying the current above and parallel to the compass needle: the needle will be deflected. Now *hold the thumb of the right hand at right angles to the fingers: place the hand on the wire with the palm downwards facing the needle and the outstretched thumb pointing in the direction in which the north pole is deflected: the fingers will be pointing in the direction of the* (*conventional*) *current* (the electronic current, of course, flows the other way).

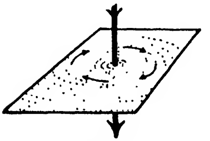


Fig. 16.

Fig. 17 shows the magnetic field and magnetic lines due to a current in a circular coil of wire. By applying the above hand rule it will be seen that if a (conventional) current flows in the coil as shown by the arrows then a compass needle placed at the centre will be deflected so that its north pole points "into the paper," *i.e.* away from the reader: in other words the direction of the magnetic field at the centre of the coil is away from the reader. If

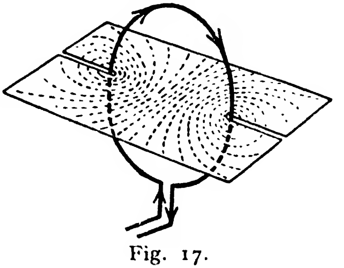
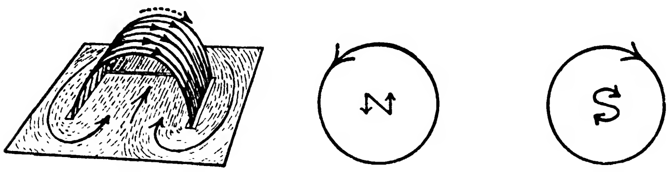


Fig. 17.

the current goes the other way, the direction of the field will be reversed.

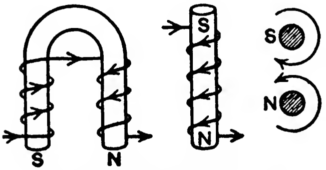
Now make a *solenoid*, *i.e.* a long coil consisting of many turns of insulated copper wire (*i.e.* wire covered with insulating material), and fix as shown in Fig. 18 (*a*). Pass a current and determine the lines by filings and the direction of the magnetic field by a compass. Reverse the current and repeat.



(*a*) (*b*)

Fig. 18.

You will find that the magnetic field of a solenoid resembles the magnetic field of a bar magnet. The lines of force leave one end of the solenoid, pass through the outside field and enter the other end (completing their circuit through the solenoid itself). In fact, the solenoid in Fig. 18 (*a*) corresponds to a bar magnet, the near end, *at which the current is circulating clockwise*, corresponding to the *south pole*, and the remote end, *where the current is circulating counter-clockwise*, corresponding to the *north pole*. Fig. 18 (*b*) will help you to remember these facts.



The arrows show the direction of the conventional current.

Fig. 19.

If you take an insulated copper wire and coil it round a bar of soft iron, as shown in Fig. 19, and start a current in the wire, the bar immediately becomes a powerful magnet, one end being a north pole the other a south pole: when the current stops the bar becomes demagnetised. The rule for the polarity is the same as that given above

for the solenoid. Magnets made in this way are called *electromagnets.*

If we have two parallel wires carrying currents in the same direction the wires tend to move together, *i.e.* we have attraction: if the currents are flowing in opposite directions we have repulsion.

Fig. 20 shows the magnetic lines of force in the case of two parallel wires when they carry equal currents in the same direction, and Fig. 21 when they carry equal currents in opposite directions. It is clear from these that there

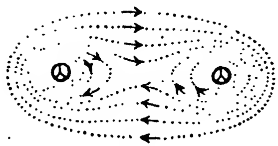


Fig. 20.

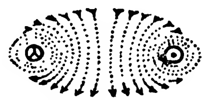


Fig. 21.

will be attraction in the first case and repulsion in the second, for lines tend to contract in the direction of their length (thus tending to bring the wires together in Fig 20) whilst lines proceeding in the same direction repel (thus tending to move the wires apart in Fig. 21).

7. The Alternating Current.

The current from a battery is what is known as a **continuous current**; that is to say, so long as the external circuit is closed, the current flows continuously in one direction. There are, however, currents which do not flow in this way but regularly reverse, flowing for a certain time in one direction and then reversing, flowing for another period of time in the opposite direction; such are called **alternating currents.**

Referring to a simple analogy, we may say continuous currents correspond to the flow of water along a pipe fed by a force pump, while on the other hand alternating currents correspond to the flow of water along a pipe leading at one time from a force pump, and at another

from a suction pump, the water being alternately forced into the pipe and then sucked back again.

Now in order to grasp the idea let us again do a little imagining as we did in Arts. 1 and 3. Suppose you have a copper wire and that an alternating current, such as is sometimes produced by a machine in an alternating current power station for electric lighting, can be sent along the wire.

Imagine you are again the "little demon" and are up against the wire having a look inside. Imagine too that your idea of time in your new condition is altogether different, so that what is really a second of time in your normal condition now seems to be 2 minutes or 120 seconds in your new condition. Now let the alternating current be switched on.

You will see, just as you saw with the continuous current of Art. 3, an army of electrons tearing along, say towards your left, but the number of electrons flowing gets bigger and bigger until finally the increase in number stops. Then the number of electrons in the flow gets smaller (although the movement is still towards your left) and this decrease in number goes on until the flow to your left ceases.

Immediately, however, electrons begin to flow along in the opposite direction, *i.e.* towards your right. Once again the number of electrons tearing along gets bigger and bigger, until finally the increase in number stops. Then the number of electrons in the flow gets smaller (although the movement is still towards your right) and this decrease in number goes on until the flow to the right ceases altogether. Immediately, however, electrons start off again in the first direction—towards your left—and the action is repeated.

A complete surge in one direction, say to the left, is called an **oscillation**, and a double surge—to the left and back again to the right—is called a **vibration.**

Now if you had noticed the time which elapsed from the moment when you had a maximum number of electrons in the flow towards, say, the left, to the moment when you had a maximum in the next flow towards the left, you

would find that it would be about two seconds of your new time, which is $\frac{2}{120} = \frac{1}{60}$ second of ordinary time. This $\frac{1}{60}$ second is called the *periodic time* or **period** of the alternating current, and the number of such intervals in one second (60) is called the **frequency** of the alternating current.

Thus the frequency is 60 per second or, as it is frequently worded, the frequency is **60 cycles per second**, a cycle being the movement from, say, a maximum in one direction through zero to a maximum in the other direction and back again through zero to a maximum in the first direction.

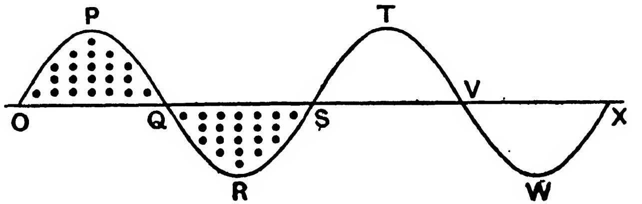


Fig. 22.

We might represent this alternating current graphically by a curve such as is shown in Fig. 22. If the curve is above the line it means that the electrons are flowing in one direction—say to the left—and if the curve is below the line it means that they are flowing in the opposite direction—towards the right. The dots indicate the number of electrons in the flow (*i.e.* the strength of the current) although each dot must really mean millions of electrons.

Thus the current strength increases from zero at O to a maximum at P, then decreases to zero at Q: then the current comes on in the opposite direction, and the strength increases to a maximum at R, then decreases to zero at S, and so on. The time taken from the condition P to the condition T (or from O to S or Q to V) is the *period*, and the number of these times in one second is the *frequency*.

The frequencies in common use are—for electric railways 25 per second, and for lighting and power 50 per second. Frequencies are spoken of as being "high" or "low," but

you must remember that such terms are purely relative. Thus 100 cycles per second might be called a low frequency as compared with one of 10,000 cycles per second, which would be called a high frequency. When the frequency rises to the order of 100,000 per second the current is generally called a **high frequency oscillatory current** or a "high frequency electric oscillation."

In wireless we really apply alternating current to the transmitting aerial in order that it may radiate energy which passes out into space in the form of waves—wireless waves—and for this to take place *very high frequency oscillatory current* is essential, as will be seen presently; in practice, this frequency used in wireless may be of the order one million cycles or more per second.

8. The Aether.

Now we must leave our electricity for a moment and consider very briefly a most extraordinary, thin jelly-like stuff which is really everywhere—inside us, in our bones and flesh, everywhere outside us—although we cannot see it or feel it or smell it.

Early scientists supposed all space and matter to be filled with a medium called the **luminiferous aether** or simply the **aether.** This medium is invisible, odourless, practically weightless, elastic: it penetrates and fills all matter and all space: we move about in it but cannot feel it for it passes easily *through* our bones and flesh: the earth, the whole universe is immersed in a limitless ocean of it. But the exact nature of it is a much discussed question.

We know that heat and light come to us from the sun and both travel millions of miles before they reach the atmosphere, and on this heat and light our very existence depends. We know also that heat and light come to us from the filaments of all electric lamps, yet many lamps are vacuum lamps, *i.e.* there is no air or gas inside—simply so-called empty space. Moreover, heat and light are both forms of energy, and in order to transfer energy from one place to another some medium was considered necessary: a medium conveying energy is always *strained* in doing so.

There must then be, it was said, beyond our atmosphere and in the lamp vacuum, some medium which can be strained. Further, many facts in science, which cannot be mentioned at this stage, demanded that this medium must exist in our atmosphere and in all forms of matter, as well as in the so-called empty spaces referred to. This all-pervading medium is the aether.

If you stand at a distance and look at a forest it appears to be a fairly solid mass of timber, yet you know that the air, and even you yourself, can get through between the trees all right. If then you think of an atom with its very, very tiny electrons a (relatively) big distance apart, and think of the aether as a very, very thin medium compared with air, you will understand how the aether can readily get through between the atoms and through the atoms themselves of what, to us, may be very solid bodies.

Incidentally, some scientists " ignore " aether altogether and say it is just a *natural property of space* that it transmits these forces—transfers this energy from place to place. However, it helps a beginner to imagine a medium—aether —so we will not argue about it here.

9. Electric Aether Strains and Magnetic Aether Strains: The Germ of Wireless.

We will go back for a moment to the electric lines of Art. 3. What exactly are these lines? Suppose, say, a positively-charged body to be brought near a suspended negatively-charged body; the latter will begin to move when the other is still some distance away. Some force is moving it and, it was said, there must be a medium to convey the force. If we move a body by pulling it with a rope or by pushing it with a stick the rope or the stick is the medium connecting the force applied and the body moved: and the rope or the stick, in transmitting the force, is *strained.* Now in the case of the two charged bodies the experiment works if they are in a vacuum, so the medium in question is not air. It was said to be the aether, and the aether conveys the force from one body to the other because it is strained. We speak therefore of an **electric**

strain in the aether, and the lines of Art. 3 really indicate the direction of the strain, and are often referred to as **electric strain lines in the aether.**

Turn again to the magnetic lines of Art. 6. What are these magnetic lines which are not visible and which cannot be physically laid hold of? If we fix our attention on a suspended magnet to which another magnet is brought near, we note that the suspended one begins to move when the other is still a distance away. Some force is moving it and, it was said, there must be some medium conveying the force; and moreover, the medium transmitting the force must be *strained.*

Now in the case of the magnets referred to, the experiment still works if the magnets are in a vacuum, so the medium which transmits the force is certainly not the air. It was said to be the aether, that substance which surrounds, permeates, and fills all matter, however apparently "solid," and all space. And the aether conveys the force from one magnet to the other because it is strained. The lines of force are lines of strain in the aether. This particular aether strain has no effect on charged bodies, but it does affect compasses, magnets, and other magnetic substances, and so it is spoken of as a **magnetic strain in the aether,** and the lines which indicate the direction of the strain are really **magnetic strain lines in the aether.**

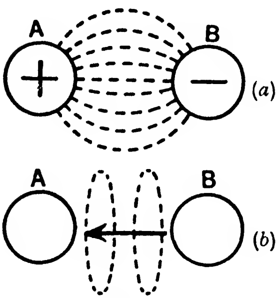


Fig. 23.

Now here is a case that occurs in wireless. In Fig. 23 (*a*) A is a body positively charged and B is another negatively charged. The aether between them is *electrically strained,* the electric strain lines being as indicated by the dotted lines.

Suppose now that A and B become discharged by sparking across the gap. This spark is really a current of electricity (a conventional one from A to B but strictly an

electronic one from B to A), and during the passage of the spark the aether is ***magnetically strained***, the magnetic strain lines being as indicated by the dotted lines in Fig. 23 (*b*).

Again, a glance at Figs. 23 (*a*) and 23 (*b*) will show that the magnetic lines of strain are at right angles to the electric lines of strain.

Now as you will see later the spark is not (under certain conditions) a mere rush of electricity from, say, B to A. It is a very rapid rush from B to A followed by a very rapid rush from A to B, followed by a very rapid rush from B to A, and so on, each rush being weaker than the previous one until in a short time it dies down. In fact it is a ***high frequency electrical oscillation***, so that we have rising and falling and alternating electric strains and rising and falling and alternating magnetic strains in the aether, and the two sets of strains are at right angles to each other. And if we can arrange matters so that the charging and discharging of A and B can be kept going on, these rising and falling electric and magnetic aether strains at right angles to each other will keep going on.

And the point is that when this particular state of affairs is brought about at any place Maxwell showed that a **wave motion** must be set up in the aether, the wave travelling outwards in a direction at right angles to both the electric and magnetic forces with the velocity of light (186,000 miles per second). With suitably constructed apparatus these are " wireless " waves, the starting point of which is therefore these electric and magnetic aether strains at right angles. Hence the importance to a wireless student of a thorough grasp of these fundamentals. All this, however, will be dealt with in detail in subsequent chapters.

CHAPTER II.

SOME UNITS AND SIMPLE ELECTRICAL THEORY.

In this chapter a very brief and simple account will be given of some important "quantities" met with in wireless, and in fact in all branches of electrical work. No attempt is made to go fully into details, for this is not necessary at this stage of your progress. On the other hand, the points dealt with are of the greatest importance, and the little that is given should be thoroughly mastered, for frequently wireless enthusiasts are "held up" owing to their lack of knowledge in this direction.

1. The Ampere and the Milliampere.

If we wish to measure a quantity of any kind we must have what we call a *unit* of the same quantity in terms of which to measure it: thus in measuring a distance we use the inch or the foot or the yard or the mile, and so on, as units. If you measured the length of a page of this book you would probably use the inch unit, but if you wanted the distance from Land's End to John o' Groats you would probably use the mile unit, for the inch unit is so small compared with the distance measured that your answer in inches would be too big a number to handle comfortably. Hence in choosing a unit we must select one of a suitable size compared with the quantities we wish to measure in order to prevent the "numbers" we have to deal with being too large or too small. This seems simple enough, but it has proved an important point in measurements connected with electricity.

Now we can get back to our subject. Consider a pipe AB, through which water is flowing steadily from A to B. Some idea of the strength of this water current may be obtained from a statement of the quantity of water entering A, leaving B, or passing any section of the pipe in a

definite time, say one second; in short, *the strength of the current may conveniently be defined as the rate of flow of water through the pipe.* Accepting, then, this definition, *the total quantity flowing past any section in a given time will be obtained by multiplying the current strength by the time in seconds.* Further, when the pipe is quite full, the quantity entering A per second must be equal to the quantity leaving B or passing any section of the pipe in that time, however uneven the bore may be; that is, *the current strength is the same at all parts of the pipe.*

The above elementary ideas have their electrical similarities. We say that *current strength is the quantity of electricity passing any section of a conductor in one second, i.e.* it is *the rate of flow of electricity in the circuit,* and clearly the total quantity which passes in a certain time will be given by the product of the current strength and the time in seconds. Incidentally this statement about current strength agrees with what we said in Chapter I., that the more electrons rushing past in one second the bigger was the strength of the current.

It follows also that the *current strength* must be the same at all parts of a simple conductor, but as we have seen the *potential* falls in the direction in which the current is flowing: these facts are clear, for if electricity is flowing along a wire, say, past the points A, B, C, then A must be at a higher potential than B and B at a higher potential than C, but the number of electrons passing A in a second must be the same as the number passing B and the number passing C per second.

Long ago a " unit " was chosen for measuring current strength, and it was a really scientific unit (most of our advanced work in Physics uses this unit), but we need not trouble you about it. When electricity began to be used in practice it was found that this unit was too large to be convenient, and so a *practical unit* one-tenth of it was taken and called the **ampere** (after the scientist Ampère): similarly a practical unit of quantity was taken one-tenth of the scientific one and was called a **coulomb** (after the scientist Coulomb).

The next point is how to get convenient definitions of the ampere and coulomb. We have seen that a current deflects a magnet: it also heats a conductor through which it passes (*e.g.* the electric glow lamp filament, the filament in a valve, the "heater" in an electric "fire," etc.): and it also decomposes or breaks up certain liquids if it passes through them (this latter is referred to as a chemical effect of the current).

Suppose, for example, we have a solution of silver nitrate in a vessel (Fig. 24), two silver plates A and K, and that we join the plates to a battery so that a current (conventional) passes through the liquid in the direction A to K. When the current has passed for some time it will be found that the plate K has increased in weight because silver has been deposited on it from the solution, whilst A will have decreased in weight because in this case silver has been taken from it to replenish the solution. If platinum plates had been used silver would have been deposited from the solution on to K, and as a matter of fact oxygen gas would have appeared at A: the silver solution would have become weaker.

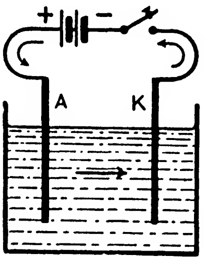


Fig. 24. Arrow shows *conventional* current.

The process of decomposing a liquid by a current in this way is called *electrolysis:* the liquid is called the *electrolyte:* the plates A and K are called the **electrodes,** the one where the (conventional) current enters the liquid, *i.e.* A, is the *positive electrode* or **anode** and the one where it leaves, *i.e.* K, is the *negative electrode* or **cathode**: the constituents which are liberated at the electrodes are called the *ions.*

Obviously, the longer the current passes in the above, the more silver will be deposited on K. Now it is found that if a current of one ampere (*i.e.* $\frac{1}{10}$ of the scientific unit) be passed through the solution it will deposit ·001118 gramme of silver every second that it flows, and this fact is used by the Board of Trade in defining the ampere. Hence:

The unit of *current strength* is the ampere: *the international ampere is that steady current which when passed through a solution of silver nitrate in water deposits silver on the cathode at the rate of* ·001118 *gramme per second.*

For most wireless reception calculations even this unit is often too big, and so we take as our unit one-thousandth part of the ampere—called a **milliampere.**

We have seen that to calculate the *total quantity* of electricity which passes in a given time we multiply the current strength by the time in seconds. Thus if 1 ampere flows for 1 second the quantity which has passed is 1×1, *i.e.* a unit quantity: if $\frac{1}{2}$ ampere flows for 2 seconds the quantity passed is again $\frac{1}{2} \times 2 = 1$, *i.e.* unit quantity. This unit quantity, i.e. *the quantity, for example, conveyed by a current of one ampere flowing for one second is called the coulomb.* If a current of one ampere flows for one hour the quantity which has passed is called an *ampere-hour*: it is evidently equal to 3,600 coulombs. And just as we calculate the quantity in coulombs by multiplying the current strength in amperes by the time in seconds, so we calculate the quantity in ampere-hours by multiplying the current strength in amperes by the time in hours.

2. The Ohm and the Megohm.

We have defined *resistance* in a general way as *that property of a body which opposes the flow of electricity through it.* Good conductors (*e.g.* metals) have small resistance, and insulators (*e.g.* glass, wax, ebonite) have large resistance. With a given applied pressure, or potential difference (P.D.) between two points, the less the resistance between the two points the bigger will be the current flowing.

Consider two points A and B in a simple conductor, and imagine a steady direct P.D. to exist between the two points; a certain steady direct current will be flowing between them. If, now, the P.D. be altered in magnitude the strength of the current will also be changed, but experimentally it can be proved that *if the temperature of the conductor be kept constant, the ratio of the P.D. to the*

current is constant; this constant is called the **resistance** of the part AB of the conductor; stated algebraically—

$$\frac{\text{Potential Difference}}{\text{Current}} = \text{a constant} = \text{Resistance.}$$

Thus if the resistance between two points were 5 units of resistance and a P.D. of 40 units were set up between them the current would be found to be 8 units (and $40 \div 8 = 5$): if the P.D. became 120 units the current would become 24 units (and $120 \div 24 = 5$).

The above is the exact definition of *resistance*, but as a matter of fact the most convenient definition of the *unit* of resistance is given in an entirely different way. Here again a certain scientific unit of resistance exists which, however, was found to be too small for practical purposes and so another one was chosen which is really one thousand million times as big and it is called the **ohm** (after the scientist Ohm). As mercury is a substance which can be obtained pure, the dimensions of a column of mercury which had a resistance of exactly one ohm were determined, and this is used in the legal definition of the ohm. Thus:

The unit of *resistance* is the ohm. *The* (*international*) *ohm is the resistance of a column of mercury* 106·3 *centimetres long,* 1 *square millimetre in cross-section* (*mass is* 14·4521 *grammes*) *at the temperature of melting ice* (0° C.).

Very big resistances are measured in **megohms**: a megohm is a million ohms. Very small resistances are measured in **microhms**: a microhm is a millionth part of an ohm.

3. The Volt and the Microvolt.

In the last section we saw that, considering any two points A and B of a wire, say, in which A is at a higher potential than B and therefore a current (conventional) is flowing from A to B:—

$$\frac{\text{Potential Difference between A and B}}{\text{Current in AB}} = \text{Resistance of AB};$$

$$\therefore \text{ Potential difference} = \text{Current} \times \text{Resistance.}$$

It is clear that if the current happens to be a unit current and the resistance happens to be the unit resistance, the P.D. will be unity. The name given to the practical unit of potential difference or pressure is the **volt** (after the scientist Volta). Hence we may say:—

The unit of *potential difference* or pressure is the volt. *The volt is the potential difference or electrical pressure which if steadily applied to a conductor of resistance one ohm will produce in it a steady current of one ampere.*

A *microvolt* is used for measuring very small potential differences: it is the millionth part of a volt.

As in the case of current strength and resistance, a certain unit of pressure exists which is based on strict scientific principles, but this unit was found to be too small for practical purposes: the volt is one hundred million times as big.

When the poles of a battery, say, are not connected, *i.e.* when the battery is on " open circuit," as it is called, the positive pole is at a higher potential than the negative pole, as we have already stated. This *potential difference on open circuit* is a characteristic of the battery (depending on the materials used in making it) and is called the **electromotive force** (E.M.F.) of the battery. It is of course measured in volts.

4. Ohm's Law.

We can now give you a very important law—known as Ohm's Law—which you will often require in wireless. In fact we have already given it, for the law is really this:— *If the temperature of a conductor be kept constant, the ratio of any steady potential difference applied to its ends to the resulting steady current through it, is constant.*

You will recognise it as what we said in Art 2, and we further said that this constant measured the resistance of the conductor. Now it is convenient, sometimes, to express quantities by letters instead of writing down the words

every time, so let E denote the potential difference, I the current strength, and R the resistance: then

$$\frac{E}{I} = \text{a constant} = R.$$

For calculation purposes it is convenient to remember two other forms of the above equation: thus from the above we get

$$E = IR \quad \text{and} \quad I = \frac{E}{R}.$$

The last one is the one usually remembered and the others are obtained from it when required. Using the various practical units we can write

Current in amperes

$$= \frac{\text{Potential Difference or Pressure in Volts}}{\text{Resistance in Ohms}}.$$

Thus if a pressure of 6 volts directly applied to a resistance causes a current of ·15 ampere to flow through it, the resistance is given thus:—

$$\text{Resistance} = \frac{E}{I} = \frac{6}{\cdot 15} = 40 \text{ ohms.}$$

Again if a pressure of 120 volts be applied to a resistance of 5000 ohms the current is given thus:—

$$\text{Current} = \frac{E}{R} = \frac{120}{5000} = \cdot 024 \text{ ampere.}$$

Finally, if a potential difference is applied to the ends of a conductor of 10,000 ohms and the current is found to be 20 milliamperes, the P.D. in volts is found thus:—

$$20 \text{ milliamperes} = \frac{20}{1000} = \frac{1}{50} \text{ ampere;}$$

$$\therefore \text{ Potential Difference} = IR = \frac{1}{50} \times 10000$$

$$= 200 \text{ volts.}$$

You will often find it necessary to work out simple calculations of this type in your wireless experiments. Thus suppose you have a valve of the 2 volt ·1 ampere type: its resistance is clearly 2 ÷ ·1, *i.e.* 20 ohms. Now suppose for some reason or other you have to use it with a 4 volt battery: as the pressure is 4 volts and the current must still be ·1 ampere, the total resistance must be 4 ÷ ·1, *i.e.* 40 ohms, so you must put a resistance of 20 ohms into the circuit. Of course more difficult cases than this sometimes crop up.

5. Conductors in "Series" and in "Parallel."

Joining conductors *in series* simply means joining them end to end so that they form one continuous road for the current like the three resistances r_1, r_2, and r_3 in Fig. 25.

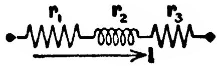


Fig. 25.

You will see at once that the total resistance is simply the separate resistances added together: thus in Fig. 25, if R denotes the total resistance and r_1, r_2, and r_3 the separate resistances, R is equal to $r_1 + r_2 + r_3$. If you have two resistances of 20,000 and 30,000 ohms respectively and you join them in series the total resistance will be 50,000 ohms.

Joining resistances *in parallel* means joining them, for example, like the three resistances r_1, r_2 and r_3 in Fig. 26: the three ends on the left are joined together at A and the other three ends are joined together at B. When a current comes up to A, say, it divides into three parts, one part flowing along each wire, the three parts uniting again at B, and passing on.

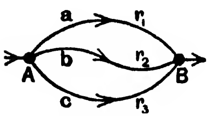


Fig. 26.

This case is not so simple as the series case. In Fig. 27, suppose A and B are two points in a conductor and that they are joined by a wire *a* of 4 ohms resistance, and that a current is flowing as shown. Now suppose we join A and B by another resistance *b* of 4 ohms (Fig. 27). Any current reaching A has now two roads instead of one: we

might almost say it is given a better opportunity of getting along from A to B, which is equivalent to saying that the resistance between A and B is less. This is perhaps a very crude and unscientific way of putting it, but it may help to drive home what is an actual fact and what may be proved both by experiment and by calculation, namely, that *when you put two or more wires in parallel between two points you lessen the total resistance between the two points:* in Fig. 27 the total resistance between A and B is really reduced to 2 ohms.

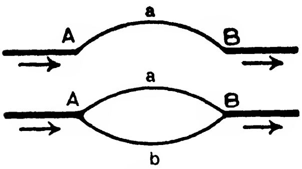


Fig. 27.

The rule for calculating the joint resistance of conductors in parallel is this: Taking Fig. 26, if R be the joint resistance from A to B we can write (this can be easily proved)

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}.$$

For example, if the three resistances be 10, 20 and 40 ohms, we have

$$\frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{40} = \frac{7}{40};$$

$$\therefore\ R = \frac{40}{7} = 5{\cdot}7 \text{ ohms},$$

that is, *the total resistance is only 5·7 ohms, which is less than the resistance of the least of them.* If two equal resistances, say, each of 300 ohms be put in parallel we have, for the joint resistance:—

$$\frac{1}{R} = \frac{1}{300} + \frac{1}{300} = \frac{2}{300}; \quad \therefore\ R = 150 \text{ ohms},$$

which is *half the resistance of one of them.* Had they been put in series the resistance would have been 300 + 300 = 600 ohms, i.e. *twice the resistance of one of them.*

6. How a Current Divides between Conductors in Parallel.

Whilst the current is the same at all parts of a simple (series) circuit, however the parts differ in resistance, in a parallel arrangement *the current divides inversely as the resistances.*

Thus if a total current of 9 amperes passes through two wires A and B in parallel, A having a resistance of 1 ohm and B a resistance of 2 ohms, it will be found that 6 amperes flow through A and 3 amperes flow through B. The following example will best show how to calculate a more difficult case.

Suppose we have three wires A, B, and C, of resistances 2, 4, and 6 ohms in parallel; that the total current is 22 amperes; and that we want to find how the current will divide, *i.e.* what the current will be in each wire. Well our solution is done thus—

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{6+3+2}{12} = \frac{11}{12}.$$

Now if our current were 11 amperes it would mean that 6 amperes would go through A, 3 amperes would go through B, and 2 amperes would go through C. Therefore—

$$\begin{aligned} \text{Current in A} &= \tfrac{6}{11} \text{ of } 22 = 12 \text{ amperes} \\ \text{,, \quad ,, B} &= \tfrac{3}{11} \text{ of } 22 = 6 \text{ ,,} \\ \text{,, \quad ,, C} &= \tfrac{2}{11} \text{ of } 22 = 4 \text{ ,,} \end{aligned}$$

You should carefully study this example before proceeding further.

7. The Laws of Resistance.

The chief laws relating to the resistance of conductors may be very briefly summed up as follows:—

(1) *The resistance of a conductor is directly proportional to its length:* 1 yard of copper wire of 20 B.W.G. (Birmingham Wire Gauge) has a resistance of ·02 ohm; hence lengths of ·5 yard and 2 yards will have resistances of ·01 ohm and ·04 ohm respectively.

(2) *The resistance of a conductor is inversely proportional to its cross-sectional area:* thus if one wire has twice the area of cross-section of another wire of the same material, and equal lengths be taken, *the thick one will have half the resistance of the thin one.*

(3) *The resistance of a conductor depends on the material:* thus a piece of platinum has nearly six times the resistance of a piece of copper of the same dimensions. In lists giving the resistances of different materials it is usual to state what is called the **specific resistance** or *resistivity, i.e.* the resistance of a cube of the material of 1 inch side (inch cube), or of a cube of 1 centimetre side (cm. cube).

(4) Metals *increase* in resistance when heated and decrease in resistance when cooled. Alloys (mixtures of metals) also *increase* in resistance when heated, but not to the extent that pure metals do: the high resistance and small variation of resistance with temperature in the case of alloys lead to their extensive use in the construction of standard resistances for testing purposes. Carbon, electrolytes, and insulators all *decrease* in resistance when heated. It should be particularly noted that insulators become *worse insulators* when heated, and some, if strongly heated, may become fairly good conductors.

The thickness of a wire is often settled by a number termed its "gauge"; thus 20 B.W.G. (Birmingham Wire Gauge) refers to a wire ·035 inch in diameter; 16 S.W.G. (Standard Wire Gauge) is a wire of ·064 inch diameter. The larger the "gauge" number the smaller is the diameter. The French Gauge is an exception to this rule.

Conductors are often formed of stranded wire on account of the greater pliability and less liability to complete break than in the case of solid wires; thus 7/22 wire refers to one whose conductor is composed of seven stranded wires, each wire of 22 gauge.

The resistance of an alloy is invariably greater than that of the substances composing it.

8. The Farad and the Microfarad.

We have seen that if we give, say, a positive charge to a conductor—an insulated brass ball, for example—we raise its potential. Suppose a charge of 20 units of electricity raised the potential of a conductor to 5 units of potential: then $20 \div 5$, *i.e.* 4, measures what we call the electrical **capacity** or **capacitance** of the conductor. Putting it in general terms, if a charge Q raises the potential of a conductor to V then the capacity of the conductor is given by the expression

$$\text{Capacity} = \frac{\text{Quantity}}{\text{Potential}}, \ i.e.\ C = \frac{Q}{V}.$$

Another way of putting it is to say that *the capacity of a conductor is measured by the quantity of electricity necessary to raise the conductor to unit potential.* Thus if a charge of twenty coulombs of electricity raises the potential of a conductor to five volts, the capacity of the conductor is $\frac{20}{5} = 4$ units (of capacity) *i.e.* the conductor requires 4 coulombs to raise it to one volt potential.

As in the other cases we have given you, there is a scientific unit of capacity or capacitance but it is not convenient for practical purposes, and so a practical unit has been chosen which is called the **farad** (after the scientist Faraday): we can define it simply as follows:—

The unit of *capacity* is the farad. *A conductor has a capacity of one farad if a charge of one coulomb raises its potential one volt.*

In wireless work the farad is too large a unit, and so we use a unit which is one-millionth of it and called a **microfarad**: a still smaller unit is sometimes encountered which is one-millionth of one-millionth of a farad and called a *micro-microfarad*.

The symbol F is often used to denote farads, μF means microfarads, $\mu\mu$F means micro-microfarads.

The name "capacitance" is better (scientifically) than "capacity." It is used in electrical theory, but capacity is still largely used in wireless work, so we will use it in this book.

9. Electrical Work and Power: Watt-hours and Watts.

We will only deal very briefly with these at this stage just in order to make you familiar with the names used. You will understand the ideas better later: do not worry much about them at present.

Whenever a potential difference exists between two points in a conductor and a current is passing between them some *energy change* is taking place between the two points. When a current flows along a copper wire energy is taken from the electric circuit appearing as heat in the wire; when a current flows through the filament of a glow-lamp, energy is again taken from the electric circuit, part appearing as heat in the filament, part being dissipated as heat given to the air and bodies near, and part being used in setting up the aether vibrations which cause light. Passing a current through an electrolyte results in the change of electrical energy into heat energy and into the energy of chemical separation, whilst passing it through a motor gives a change into heat and mechanical work. In all cases the electrical energy which disappears is equivalent to the new forms into which it is changed.

Now in electrical engineering the unit of *electrical energy* or *electrical work* is called a **watt-hour.** If the pressure at the terminals of an electric lamp, say, be E volts and the current passing be I amperes, and if this current flows for T hours, then the total electrical energy in watt-hours absorbed by that lamp in that time is calculated thus:—

$$\text{Energy in Watt-hours} = \text{Volts} \times \text{Amperes} \times \text{Hours};$$
$$\therefore \text{Watt-hours} = EIT.$$

Clearly if E, I, and T are each unity the energy in watt-hours is unity; hence *if the pressure between two points is one volt and one ampere flows for one hour the electrical energy taken by the circuit between the two points is one watt-hour.*

A larger unit of electrical energy is used by the Board of Trade: it is called a *Board of Trade Unit* and is equal to 1000 watt-hours. Thus to find the number of Board of

Trade Units of electrical energy consumed by, say, an electric lamp, you calculate the watt-hours as above and then divide by 1000: you pay perhaps 6d. to your local electrical people for every Board of Trade Unit of electrical energy consumed.

Now *electrical power means the rate at which the electrical energy is consumed or the electrical work done,* i.e. *it is measured by the electrical energy or work per second.* In electrical engineering the unit of electrical power is called a **watt.** If the pressure at the terminals of an electric lamp, say, be E volts and the current passing be I amperes, the power absorbed by the lamp is calculated thus:—

$$\text{Power in Watts} = \text{Volts} \times \text{Amperes};$$
$$\therefore \text{Watts} = EI.$$

Clearly if E and I be unity the power in watts is unity; hence *if the pressure between two points is one volt, and one ampere is flowing, the power in the circuit is one watt.*

Thus if the output valve of a wireless receiver takes 15 milliamperes at 150 volts, the total power is $150 \times \frac{15}{1000} = 2{\cdot}25$ watts or 2250 milliwatts, but much less than this —about one-quarter—is *usefully* employed on the loud speaker. Six milliwatts of useful power will work head-phones; 200 will work a speaker for a small room; 600-1000 (1 watt) will work a moving coil speaker at good volume, though less may be used; for high class performance 1½–3 watts are required.

A larger unit of electrical power is also used: it is called the *kilowatt* and is equal to 1000 watts.

Incidentally a mechanical engineer measures his power in units called horse-power: it takes 746 of the electrical engineer's watts to be equivalent to the mechanical engineer's horse-power.

There is still another important quantity and its unit which will be frequently met with later, viz. *inductance* and its unit the *henry* (named after the scientist Henry), but we cannot deal with these until we come to Chapter IV.

CHAPTER III.

DRY BATTERIES AND ACCUMULATORS.

1. General Principles.

If a piece of common zinc be placed in dilute sulphuric acid a violent action takes place, the zinc being eaten away, hydrogen gas given off, and what is called zinc sulphate formed.

If we *amalgamate* our zinc, *i.e.* coat its surface with mercury and place it in the acid no action will be observed; and further, if we put a piece of copper in the acid no action will be observed.

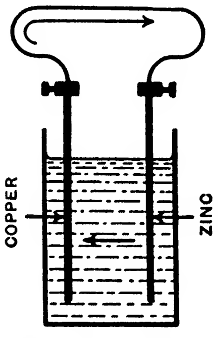


Fig. 28. Arrow shows *conventional* current in wire.

If a plate of copper and a plate of amalgamated zinc be put, say, opposite to each other in the acid, but not touching, again no action will be observed. But if they be connected outside by a copper wire (Fig. 28) it will be found that (*a*) the zinc is eaten away, (*b*) hydrogen gas appears at the surface *of the copper plate*, and (*c*) a current of electricity (conventional current) flows in the circuit in the direction copper to zinc in the connecting wire, zinc to copper in the liquid (the electronic current—the movement of electrons which is the real current—goes the other way).

Such an arrangement as the above is called a simple voltaic **cell.** The copper plate is at a higher potential than the zinc and is known as the *high potential plate*, the portion of it outside the acid being called the *positive pole* of the cell; the zinc is known as the *low potential plate*, and the portion of it outside is called the *negative pole*. In the

outside circuit the (conventional) current flows from the high-potential copper to the low-potential zinc; inside the cell the energy of the chemical action is used in *forcing* the electricity from the low to the high potential. The chemical action in the cell is, in fact, similar to that of a pump lifting water from a lower to a higher level, from which position the water would naturally run down again, doing work in virtue of the energy conferred upon it. Thus in the cell the consumption of the zinc really furnishes the energy which maintains the current in the circuit.

As already mentioned, when the cell is on "open circuit," *i.e.* before its poles are joined and a current passing, the potential difference between the positive pole and negative pole is called the *electromotive force* (E.M.F.): when the current flows the potential difference between the poles is less than the E.M.F. The E.M.F. of a simple cell is roughly about one volt.

It frequently happens that a single cell of any kind is insufficient to do what we want, and we then use a combination of several cells: such a combination is called a **battery.**

There are still two more points we must mention before leaving our simple cell. Common zinc contains many impurities, such as iron, lead, arsenic, etc.; when such a piece of zinc is put in acid, these impurities together with the zinc being in contact with the acid give rise to a number of local currents all over the surface of the plate, the result being that the zinc is consumed without any advantage being gained therefrom. This, termed **local action,** is prevented by *amalgamating* the plate, *i.e.* coating its surface with mercury. The latter dissolves the zinc, forming a uniformly soft amalgam which covers up the impurities; as the zinc is consumed the impurities fall to the bottom of the cell. Local currents between portions of the plate differing in hardness are also prevented by this device.

Again we saw that when the copper and zinc were joined outside and a current flowed, bubbles of hydrogen gas appeared *at the copper.* This is readily explained by the

fact that positive hydrogen ions *do* travel through the liquid towards the copper plate (and negative ions travel the other way through the liquid towards the zinc plate). This deposition of hydrogen on the copper is called **polarisation**: it weakens the current and spoils the cell in two ways: (1) the gas has a large resistance, (2) a *back E.M.F.* is set up which, acting in the opposite direction, reduces the main E.M.F. of the cell. The modern primary cells are mainly devices for doing away with, or at least lessening, polarisation, by, so to speak, using up the hydrogen.

2. The Leclanché Cell and the Dry Cell.

The low potential element of the Leclanché cell (Fig. 29) consists of a rod of zinc placed in a solution of ammonium chloride (sal-ammoniac) contained in a glass vessel. A rod of carbon forms the high-potential element; this is placed in a porous earthenware pot, and is surrounded by broken carbon and black oxide (dioxide) of manganese. The chemical action between the zinc and the ammonium chloride causes hydrogen to be liberated and this if allowed to accumulate at the carbon would cause polarisation. But an action takes place between the hydrogen and the manganese dioxide with the result that water and a brown oxide of manganese are formed: thus hydrogen does not appear and polarisation is prevented.

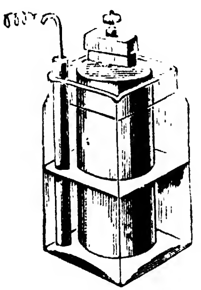


Fig. 29.

In practice, however, the hydrogen is liberated more quickly than the manganese dioxide can use it up, so that after a time polarisation sets in and the current falls off. If the cell is allowed to rest the manganese dioxide performs its work and the cell more or less regains its strength; thus Leclanché cells are adapted for intermittent work, such, for example, as bell-ringing and telephone calls. The E.M.F. of the cell is about $1{\cdot}5$ volts, and its resistance may amount to several ohms.

There are many cells on the market known as **dry cells,** and they are really modifications of the Leclanché in general principle. Further, they are not strictly "dry": if they were they would not work. One type, shown in Fig. 30, consists of a zinc cylinder *Zn* next to which is a paste W composed of plaster of Paris, flour, zinc chloride, sal-ammoniac, and water. Adjoining this is a second paste B of carbon, manganese dioxide, zinc chloride, sal-ammoniac, and water. C is a rod of carbon, forming the high-potential plate of the cell. The whole is covered with a case of millboard, is sealed with pitch, and is provided with a vent for the escape of gas. The manganese dioxide "uses up" the hydrogen and more or less prevents polarisation. The E.M.F. is about 1·4 volts.

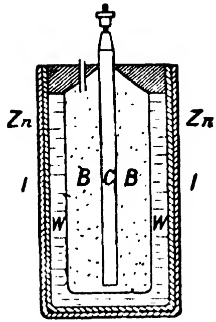


Fig. 30.

The main points in favour of dry cells are: (1) they are compact and portable; (2) they may be placed in any convenient position; (3) they require very little attention; (4) they are more cleanly than the ordinary type of Leclanché.

It should be noted in passing that the E.M.F. of a cell depends on the materials employed in its construction (and on the temperature), but it does not depend on the size of the plates or on their distance apart. The internal resistance does, of course, depend on the size of the plates and on their distance apart; the larger the plates and the nearer they are together the less the resistance.

3. Batteries.

Cells grouped together are spoken of as *batteries* and there are two types, viz. *series batteries* and *parallel batteries,* but the former is the arrangement you will generally meet with.

The series grouping is shown diagrammatically in Fig. 31: the negative pole of the first cell is joined to the positive

pole of the second, the negative of the second to the positive of the third, and so on, so that at one end of the battery we have a positive pole and at the other end a negative pole, and these are coupled to the circuit outside in the usual way. If we have 100 cells, exactly alike, joined in this way and the E.M.F. of each is 1·5 volts, the total E.M.F. of the battery will be 1·5 × 100, *i.e.* 150 volts. If the internal resistance of each cell is ·2 ohm the total internal resistance of the battery will be ·2 × 100, *i.e.* 20 ohms (the internal *resistances* are *in series*). If the poles of the battery are joined to an outside circuit, say, of 1480 ohms, the current through this outside circuit will be

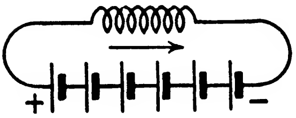


Fig. 31.

Current in Amperes

$$= \frac{\text{Pressure (E.M.F.) in volts}}{\text{Resistance in ohms}} = \frac{150}{20 + 1480};$$

$$\therefore \text{ Current} = \tfrac{1}{10} = \cdot 1 \text{ ampere.}$$

The parallel grouping is shown in Fig. 32: all the negatives are joined together to form as it were one large negative element, and all the positives are joined to form one large positive element, and the outside circuit is connected to the poles as before. Since the E.M.F. of a cell does not depend on the size of the plates, the combined E.M.F. is *just the same as the E.M.F. of one cell.* You do not gain anything in E.M.F. by joining cells in parallel, so that if we have the same 100 cells as in the previous example, the E.M.F. of the battery is only 1·5 volts. But the internal resistances are *in parallel* and the resistance of 100 equal resistances in parallel is one-hundredth of the resistance of one of them: in the present case ·2 ÷ 100 = ·002 ohm. You do gain

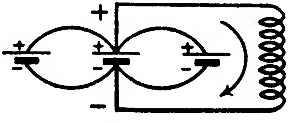


Fig. 32.

then as far as a less internal resistance is concerned. If the outside resistance is the same as before, viz. 1480 ohms, the outside current will be

$$\text{Current (amperes)} = \frac{\text{E.M.F. (volts)}}{\text{Resistance (ohms)}} = \frac{1{\cdot}5}{{\cdot}002 + 1480};$$

$$\therefore \text{ Current } = {\cdot}001 = \tfrac{1}{1000} \text{ ampere (nearly).}$$

Notice that in the example we have worked out the outside resistance is a large one (1480 ohms) compared with the internal resistance of the battery, and that the series grouping gives a much bigger current.

Let us take an exactly opposite case and assume that the outside resistance is small compared with the inside resistance—say it is only $\frac{1}{10000}$, *i.e.* ·0001 ohm—and work out the current in the outside circuit. We get the following results:—

$$\textit{Series} \quad \text{Current} = \frac{150}{20 + {\cdot}0001} = 7{\cdot}4 \text{ amperes.}$$

$$\textit{Parallel} \quad \text{Current} = \frac{1{\cdot}5}{{\cdot}002 + {\cdot}0001} = 714{\cdot}3 \text{ amperes.}$$

In this case the parallel grouping gives a much bigger current. Thus we can say in a general way that *a series grouping will give a bigger current when we have a large external resistance* to contend with, and *the parallel grouping lends itself to a small external resistance.* As a matter of fact the parallel grouping is very rarely required or used.

If cells of different E.M.F.'s are in series the total E.M.F. is the sum of the separate E.M.F.'s, and the total internal resistance is the sum of the separate resistances. If cells of different E.M.F.'s are in parallel matters become a little complicated: it is rarely advisable to join different E.M.F.'s in this way.

4. Dry Batteries in Wireless.

In valve receiving sets in wireless using batteries, dry cells *in series* are almost invariably employed for what is called the **high tension (H.T.) battery**—a battery which is

used to applv a high positive potential to the plates of the valves. High tension batteries may have an E.M.F. of from 50 volts to 300 volts or more, according to circumstances, and as the E.M.F. of a single dry cell is of the order 1·4 volts, it will be seen that the number of cells in a high tension battery will vary from, say, 30 or so to quite large numbers.

High tension batteries are usually suitably arranged in strong cardboard boxes, the cells being well sealed in with paraffin wax or pitch. Tappings are taken from every third or fourth or sixth, or tenth, etc., cell and connected to a hollow metallic socket, the upper open end of which projects above the wax (Fig. 33). The positive and negative battery leads from the receiving set are attached to metallic pins, known as *wander plugs*, which fit into these sockets: in this way the voltage actually used can be varied. Graduated scales alongside the sockets or numbers opposite the sockets indicate the voltage which is being tapped.

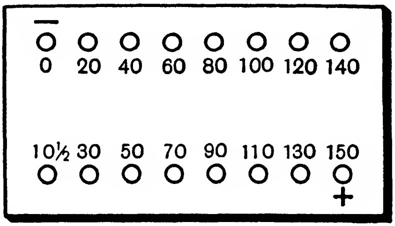


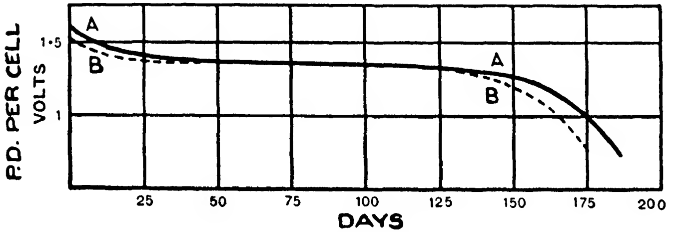
Fig. 33. Top of a High Tension Battery.

It should be remembered that polarisation sets in with dry cells if kept in use for a long time and local action, etc., may occur even if standing idle for a long time. In the former case they partly recover with rest: the latter defect is only small in the case of the best batteries, *i.e.* good batteries have a good **shelf life.**

A large number of high-tension batteries for wireless receivers is on the market and unfortunately the purchaser is too often inclined to be "put off" with any make provided its voltage is apparently correct—and perhaps also if it is cheap. This is a mistake, for not only may the life of the battery turn out to be very short, necessitating another purchase, but the reception after a few days may

be far from satisfactory. So vital is this that, for beginners, we will refer to one or two reliable types.

A battery which ranks amongst the really good ones on the market is that known as the *Full o' Power* made by the well-known firm of battery makers, Messrs. Siemens. We have personally subjected this battery to careful laboratory tests, to continuous working over long periods, to excessive discharges and to rough usage, and it has proved itself most efficient. Its resistance is comparatively low, its E.M.F. is wonderfully constant—its E.M.F.-time curve remaining practically horizontal for long periods—and it has excellent powers of recovery. It is a reliable long-life steady battery which we confidently recommend.



A, Discharge at 10 milliamperes for 3 hours per day. B, Discharge at 10 milliamperes for 3 hours per day after 8 months' storage.

Fig. 34.

In the *Full o' Power* the zinc takes the form of a *seamless cylindrical container* or can instead of the usual form of a sheet of zinc bent into a cylinder with the edges soldered together: specially pure zinc is used, thus reducing local action and securing a good shelf life. The containers are lined with special paper into which the depolarising mixture is heavily compressed, thus ensuring a maximum amount of such material and a more uniform potential for the cell. The depolarising material is very effective so that the E.M.F. is practically constant for the whole life of the cell, as can be seen from the discharge curves of Fig. 34. The cells are sealed in such a way that it is possible to relieve gas pressure from inside and at the same time prevent the

essential moisture from evaporating (moisture is essential in a "dry" cell). In insulating the cells leatherboard impregnated and coated with paraffin wax is used, each cell being completely surrounded by the insulating material. The carbon stands in the centre of the cell and the brass cap for connecting purposes is tinned to ensure a good soldered joint.

The *Full o' Power* battery can be obtained in three types—the "Standard," the "Power," and the "Super-Radio"—and at various voltages.

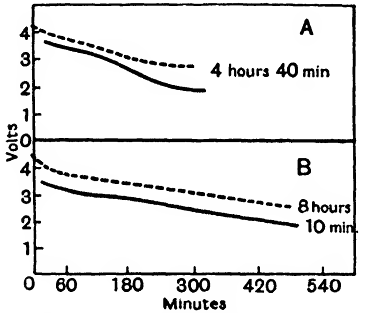


Fig. 35. Discharge after 3½ months storage.

A = Sal Ammoniac, B = Magnesium Chloride : Voltage at beginning = - - - - : Voltage at end = ————.

Another very reliable high-grade battery, also made by a firm of repute —the Chloride Electrical Storage Co. Ld.—is the *Drydex*. The battery can be obtained in three different capacities, the ordinary, the intermediate, and the super, and of voltages up to 120.

In the *Pertrix* battery of the Britannia Batteries Co., magnesium chloride is used instead of sal-ammoniac. The latter has a corrosive action on zinc which affects somewhat adversely the useful life and keeping properties, and moreover the recuperative powers decrease as corrosion advances: magnesium chloride has no powerful corrosive action on zinc. Thus the outstanding features of Pertrix batteries are the remarkably long life, long shelf-life, higher initial voltages, and decided recuperative power during periods of rest: some of these points will be gathered from the curves shown in Fig. 35. We have tested the *Pertrix* over long periods of heavy discharge and can state it to be an excellent battery. It is obtainable in different capacities.

It is better to purchase a *high-capacity battery* (see later) at the outset: the longer life and better reception more than compensate for the somewhat higher initial outlay.

There are other good batteries on the market, but space does not allow us to go into details.

It is invariably necessary, in receiving sets employing several valves, to apply a positive or negative potential to the grid of a valve, as will be explained later: usually this is done by means of a few dry cells, the latter being then referred to as a **grid biasing battery**.

5. Accumulators or Secondary Cells.

If water with just a little sulphuric acid in it be decomposed by passing a current through it (as we did with silver nitrate in the last chapter), the electrodes being platinum plates, and if, when the action has continued for some time, the battery be disconnected and the electrodes joined by a wire, it will be found that for a short period a current flows in the direction *anode to cathode through the connecting wire.* This was employed by Ritter in the construction of the earliest secondary cell or accumulator.

In the usual accumulator lead plates are employed. Consider two such plates, A and K (Fig. 36), immersed in dilute sulphuric acid (ten parts by weight of water to one of acid), and let a current of electricity be passed through from A to K. The acidulated water will be decomposed into the two gases, hydrogen and oxygen, the oxygen appearing at the anode A, the hydrogen at the cathode K. The oxygen at the anode combines with the surface lead forming a dark brown peroxide of lead, as it is called; the hydrogen at the cathode mostly rises to the surface, so that this plate remains in the metallic state.

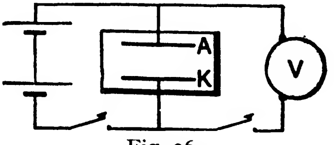


Fig. 36.

When the "charging" process, as it is termed, has continued for some time, let the battery be disconnected and the plates A and K joined through a voltmeter V, which

is an instrument which measures the volts; the instrument will indicate about 2 volts at first, a current will flow through the outside circuit in the direction A to K, and, decreasing gradually, will after a time cease. On examining the plates it will be found that the peroxide has disappeared, and that both plates have what is called lead sulphate formed on them.

The charging process may now be repeated by passing a current through the liquid in the direction A to K. The liberated oxygen at A will convert the lead sulphate there into lead peroxide, while the hydrogen at K will reduce the products there to the metallic state; thus the electrodes are again in their " formed " condition, viz. lead peroxide at A, lead at K.

Such an arrangement is termed a **secondary cell,** *storage cell,* or **accumulator**; the *anode* is called the *positive plate,* and the *cathode* the *negative plate* of the cell. It should be particularly observed, however, that there is no accumulation or storing of electricity; what takes place is the change of electrical energy into the potential energy of separated ions, *i.e.* into " chemical potential energy "; and when the cell gives a current the energy change is merely reversed.

In the above it is mentioned that on the first " charge " the plate K remains more or less in its initial condition, and as such it does not readily tend to form lead sulphate at discharge. This defect is eliminated by adopting the " alternate " charge process introduced by Planté. The current is first passed through the electrolyte in the direction A to K, with the result that A is peroxidised; it is then reversed, in which step the oxygen at K forms lead peroxide there, while the hydrogen at A reduces the existing peroxide to porous spongy lead. This operation is several times repeated, with the final result that the last anode (positive plate) has a thick coating of dark brown lead peroxide, while the last cathode (negative plate) is coated mainly with metallic lead of a greyish colour in a porous spongy condition. The process is known as " forming " the plates.

To obviate the tedious "formation" of the Planté plates, Faure coated the plates, prior to charging, with a paste of red lead and sulphuric acid. On charging, the red lead on the cathode becomes quickly reduced to spongy metal, while that on the anode becomes peroxidised. Later the Sellon-Volckmar plates were introduced, which, being constructed in the form of grids, more effectively secured the paste. Thus accumulators follow in general two types—(1) the Planté or naturally "formed" cell, and (2) the Faure or pasted grid cell.

The poles of an accumulator are generally distinguished by painting the terminal of the anode or positive plate red, and that of the cathode or negative plate black.

In battery receiving sets accumulators are nearly always used for the purpose of heating the filament of a valve, and are known as *filament batteries* or **low tension (L.T.) batteries.** Such may consist of one accumulator (2 volts), two accumulators in series (4 volts), or three accumulators in series (6 volts), according to the valves employed.

Accumulators are also employed as high tension batteries in some cases: it is more usual, however, to use dry cells.

The E.M.F. of an accumulator, whether large or small, is about 2 volts, but the current which can be taken from it depends, amongst other things, upon the size of the plates and their distance apart. To obtain large currents with plates of reasonable dimensions the arrangement shown in Fig. 37 is adopted. This shows a large thirteen plate cell, the positive consisting of six positive plates P connected together, and the negative consisting of seven negative plates N similarly connected together: thus each positive has a negative on both sides of it.

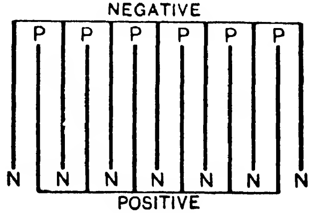


Fig. 37.

To keep the internal resistance as low as possible the individual plates are placed very near each other. To

prevent internal contact between these plates, separators are placed between them; thus the Chloride Co. use sheet separators of specially prepared thin wood (Fig. 38).

There must be a good space between the plates and the bottom of the containing vessel to hold any active material which may fall from the plates, so that such material may not join two opposite plates, thus short circuiting the cell and spoiling it. With the larger cells contained in glass boxes, the usual practice is to provide the plates with projecting shoulders which enable them to be suspended at the correct height from the edges of the containing vessel. Supporting blocks of wood or vulcanite placed in the bottom of the cells are other usual methods. Incidentally, the containing vessels for wireless accumulators are usually of best quality celluloid: also celluloid lids are generally sealed to the tops of the cases, thereby preventing impurities from entering the cells, and eliminating the possibility of the metal terminals becoming corroded owing to the flooding and creeping of the acid.

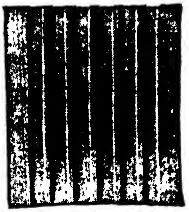


Fig. 38.

The **capacity** of an accumulator is measured in *ampere-hours:* thus if a large accumulator has a capacity of 704 ampere hours and the greatest discharge current as stated by the makers is 64 amperes, it will be able to give this current for 11 hours.

For some purposes accumulators are designed to give a certain current on a 9 or 10 hour discharge rate, *i.e.* the best results are obtained if the current taken from the cell be such that it is discharged in 9 or 10 hours (sometimes details are given by the makers based on a 20 or a 100 hour rate). Thus on the 10 hour rate if an accumulator is stated to have a capacity of "30 ampere-hours actual," then, since $\frac{30}{10} = 3$, good results will be obtained by taking a current of 3 amperes from the cell. Further, this accumulator would deliver a current of $1\frac{1}{2}$ amperes for more than 20 hours, for *the capacity of an accumulator*

increases if the discharge current is reduced, i.e. its capacity is more than 30 ampere-hours when discharged at a less current value than 3 amperes. On the other hand, the accumulator would not deliver 6 amperes for 5 hours, for *the capacity decreases as the discharge current increases.*

The maximum discharge rate as specified by the makers should never be exceeded, otherwise the intense chemical action and heat produced will result in unequal expansion of the plates, excessive formation of a *hard* lead sulphate, loosening of the paste, and bending or buckling of the plates—the last named producing internal short circuits, and eventually spoiling the cells. For like reasons, accumulators should never be short circuited outside, for their internal resistance is so low (of the order ·001 ohm, depending on the number and size of plates and their distance apart) that heavy discharge currents will flow, and sulphating, disintegration, and buckling will follow. Sulphating is indicated by a hard white surface forming on the plates: this hard sulphate must not be confused with the ordinary sulphate produced on discharging.

When an accumulator is discharged two factors are affected, viz. the specific gravity of the acid and the voltage of the cell: both of these decrease, and both may be used to indicate the condition of the cell.

The values of the specific gravity vary with the type of accumulator, but in a general way it may be stated that (1) when fully charged the specific gravity is about 1·25, (2) when half discharged it is about 1·18, and (3) when fully discharged it is about 1·11. It is, however, best to be on the safe side, and to consider a drop in specific gravity to 1·15 to be an indication that the cell should be re-charged: if run below this value there is always the possibility of the plates sulphating. Instruments known as *hydrometers* are used for testing the specific gravity.

When fully charged, the E.M.F. of a cell is just over 2 volts—frequently 2·2 volts. When the cell is supplying a current, the E.M.F. drops fairly quickly to 2 volts, remains at about 2 volts over a long period, and then gradually falls. When it reaches 1·8 volts (current flowing) the cell

should be regarded as discharged: it should never run below this value, otherwise sulphating and buckling of the plates may follow. It may be noted in passing that in a general way the positive plates of a fully charged cell are of a deep chocolate colour, whilst the negatives are of a slate-grey colour: these colours are a guide to the condition of the cell.

Accumulators should be kept well charged; they should on no account be permitted to stand for any length of time in an uncharged condition, or the amount of hard sulphate will become excessive. When not in use short chargings should be given occasionally, say fortnightly, till the plates gas freely.

Any evaporation of the electrolyte must be compensated for by an addition of pure water: the acid must always be kept above the level of the tops of the plates. Incidentally, when diluting strong acid for use with accumulators, the acid should be poured into the water, not the water into the acid.

When an accumulator is being re-charged the proper value of the charging current as stated by the makers should be passed for the number of hours also stated, and the battery must not be used until the acid in each cell has turned milky and gas is freely evolved from both plates, nor until the specific gravity of the acid has ceased to rise.

The **quantity efficiency** of an accumulator is given by the expression:—

$$\text{Quantity Efficiency} = \frac{\text{Ampere-hours given out}}{\text{Ampere-hours put in}},$$

and is of the order 85 to 90 per cent. (it may reach 95 per cent. if discharge immediately follows charge).

The **energy efficiency** of an accumulator is given by the expression:—

$$\text{Energy Efficiency} = \frac{\text{Watt-hours given out}}{\text{Watt-hours put in}},$$

and is of the order 65 to 75 per cent.

There are many types of accumulator plates on the market. Fig. 39 shows one type of negative plate and

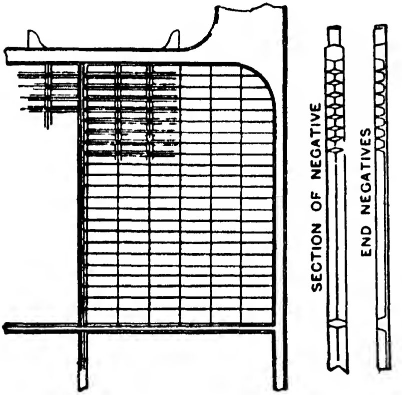


Fig. 39.

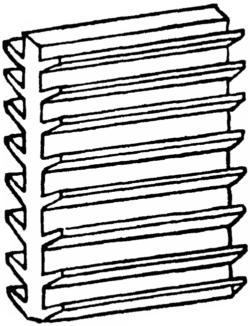


Fig. 40.

Fig. 40 one type of positive plate. The paste for the negatives is made of pure well-ground litharge and sulphuric acid of specific gravity 1·2 (cold): the paste for the positives consists of red lead and sulphuric acid of specific gravity 1·1 (cold).

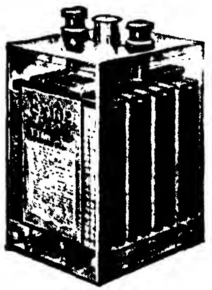


Fig. 41.

A typical example of a complete reliable modern accumulator for wireless work is shown in Fig. 41. It is a 2 volt *Exide* made by the Chloride Co.: its actual capacity at the 100 hour rate is 80 ampere-hours and at the 20 hour rate 52 ampere-hours. The *Hart* also is an excellent accumulator: the plates are particularly robust and the cells very steady and lasting in their performance. The *Pertrix*, another reliable accumulator, is fitted with a floating bead which indicates the condition of the cell and when re-charge is necessary.

CHAPTER IV.

CAPACITY AND INDUCTANCE: CONDENSERS AND TUNING COILS.

It might almost be said that the two essentials of a wireless installation are **capacity** (or capacitance) and **inductance,** for it is upon these that two factors about which you will have heard so much—the *wave length* and the *frequency* of the wireless waves—depend. Capacity and inductance govern the wave length of the waves sent out by a broadcasting station, and when you "tune in" to any particular station you alter the capacity or inductance or both of your receiver in order to make it accept that particular wave. You will understand this later.

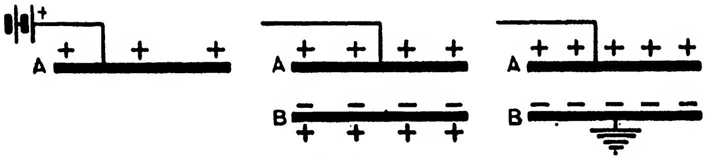


Fig. 42.

1. The Principle of a Condenser.

To simplify matters we will treat this from the point of view of the older as well as the newer theory of electricity. Consider a metal plate A (Fig. 42) joined by a wire to the positive pole of a battery or some other electrical generator. Electricity flows to A until the plate acquires the potential V of the generator: then no further charge can be accumulated on A, for electricity will not flow between two bodies whose potentials are the same. It is, moreover, evident that the larger the plate the greater will be its capacity (page 39), and therefore the greater the charge necessary to bring it up to the potential of the generator.

Take, now, a second insulated metal plate B, and place it parallel to, and a short distance from A. Inductive displacement occurs (page 9): the top side gets a negative charge, the bottom side a positive charge, and the uniform potential of B is v, say, this being less than V in magnitude.

Now consider the effect of B on the potential of the plate A. The actual potential of the latter is the resultant of—(1) the free positive potential V due to its own charge, (2) the induced negative potential due to the negative charge on B, and (3) the induced positive potential due to the positive charge on B. The two latter opposing influences nearly counteract each other; but the negative charge, being somewhat nearer than the positive, has the advantage, and therefore on the whole *the potential of the plate* A *is weakened a little*. Clearly, then, an additional charge can now be given to it from the generator until its potential is once more equal to V as at first. Clearly also the nearer B is to A the more marked will be the lowering of the latter's potential.

If B be now earthed, electricity will flow out of it until its potential is reduced to zero. B has now a negative charge only (as a matter of fact, *a greater negative charge than before*, but we need not explain this). The increased negative charge reacting on A lowers the latter's potential, and as there is no positive to counteract its influence, it is evident that *the potential of* A *will be considerably weakened*, and, in consequence, a much greater charge must be given from the generator to raise the potential to its original value V—in short, *the capacity of* A *is considerably increased.*

Such an arrangement of conductors separated by an insulator (air in this case) is called a **condenser**: the conductors are usually spoken of as the **plates** or *coatings*, and the insulator as the *dielectric* of the condenser.

In practice condensers are usually charged by means of batteries, A being joined to the positive pole of the battery and B to the negative pole. This simply means that whilst A takes the positive potential of the positive pole of the battery, B, instead of being at zero potential, takes the negative potential of the negative pole of the battery: and

there is a big positive charge on A and a big negative charge on B. The action and explanation, in fact, are similar to the preceding.

Some solid (and liquid) insulators, *e.g.* glass, wax, mica, etc., allow inductive influence to take place through them better than air and are said to have a higher dielectric constant or specific inductive capacity; with one of these substances as dielectric the effects mentioned would be still more marked. For this reason, and also owing to their greater mechanical rigidity, solid dielectrics of glass, wax, and mica are frequently employed in practical condensers.

We will now look at the action of a condenser from the point of view of the electron theory. Imagine a condenser joined to a battery, A to the positive and B to the negative pole. As soon as the connections are made there is a momentary rush of electrons (negative) from the negative pole of the battery to B, and electrons rush out of A to the positive pole. Thus on B, we have an excess of electrons, whilst on A, we have atoms which have each lost an electron—*positive ions* as they are called (Chapter I.).

The positive ions of A and the negative electrons on B attract each other with an intense force. The army of electrons on B is anxious to get across the dielectric to the positive ions of A, and the positive ions of A are just as eager to have them. Now the electrons on B cannot themselves get across the dielectric (insulator) to A but they do, as it were, the next best thing—they *try* to drive electrons out of the atoms of the dielectric (themselves taking their place), leaving these evicted electrons to drive out other electrons and take their place, and so on until finally electrons would reach A. At the same time the positive ions of A are assisting in the work by trying to pull out the electrons and to repel the resulting positive ions in the dielectric.

The dielectric, however, is a substance which clings to its electrons: it contains practically no detachable electrons. All that happens therefore is that the orbits of the electrons round the positive nucleii (or protons) in the atoms of the

dielectric are *strained* as shown in Fig. 43: the positive nucleus of any dielectric atom is pushed by A and pulled by B down towards the electrons on B, and the electrons in any dielectric atom are pulled by A and pushed by B up towards the positive ions of A. The final state of affairs is that the plate A draws a large positive charge from the battery and B a large negative charge, *the medium is strained*, and we have what is spoken of as a *charged condenser*, but no " flow of current " across the dielectric. The strain lines are shown in the right-hand side of the figure.

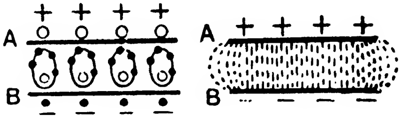


Fig. 43.

Condensers, as already mentioned, are largely used in wireless for " tuning " the receiver to the waves from different stations. And they are used for other purposes, *e.g.* as " blocking " condensers to stop direct current (for such a current cannot flow through them), and as " by-pass " condensers for oscillatory current (for such a current can " work through " them—see Chapter V.). Incidentally the aerials used in wireless are condensers, the wire forming the one coating, the earth and earth-joined bodies the other coating, the intervening air being the dielectric: of course this capacity is small.

2. Capacity or Capacitance of a Condenser.

In defining the capacity of a body in Chapter II. we said it was measured by the quantity of electricity necessary to raise it to unit potential, *i.e.* if a body required 5 *units of electricity* to raise its potential 1 *unit of potential* its capacity was said to be 5 *units of capacity.* The capacity of a condenser is defined similarly, only in this case we use the words " between the coatings ": thus—

The capacity of a condenser is measured by the quantity of electricity which must be given to it to establish unit potential

difference between the coatings. If one coating be earthed the capacity of the condenser will be measured by the quantity of electricity necessary to raise the other coating to unit potential, *i.e.* the capacity of the condenser is numerically the same as the capacity of the plate A if B is earthed.

Now, as already explained, the practical unit of capacity is the **farad**: *a condenser has a capacity of one farad if a charge of one coulomb produces a potential difference of one volt between the coatings.* In wireless, capacities are more often expressed in **microfarads** (page 39), the microfarad being one millionth of a farad. A micro-microfarad is one millionth of one millionth of a farad (page 39). From the definition it follows that if C be the capacity of a condenser in farads, Q the charge given to it in coulombs, and V the potential difference between its coatings in volts,

$$C = \frac{Q}{V}; \quad \therefore\ Q = CV; \quad \therefore\ V = \frac{Q}{C}.$$

These are often required in calculations. You should remember them: also recall them in words.

We have mentioned that some dielectrics allow inductive influence to take place through them better than air and are said to have a higher **dielective constant** or *specific inductive capacity.* For example, if an air condenser like that of Fig. 42 has a capacity of ·0002 microfarad, and if the space between the plates be then filled completely by mica, the capacity of the mica condenser so formed will be about (·0002 × 6·6), *i.e.* ·00132 microfarad. 6·6 is the dielectric constant of mica.

From what has been said it follows that the capacity of a condenser depends on: (1) the size of the plates—the larger the plates the greater the capacity, (2) the distance between the plates—the less the distance the greater the capacity, (3) the dielectric constant or specific inductive capacity of the dielectric—the greater the value of the dielectric constant the greater the capacity.

3. Joining Condensers (or Capacities) in Series and in Parallel.

We can join condensers in *series* or in *parallel* just as we join resistances in series or in parallel, but there is an important difference which you must carefully notice.

We will take the *parallel* arrangement first. A parallel grouping is shown in Fig. 44: in it, all the *a* plates are joined together and connected say to the positive pole of a charging battery, and all the *b* plates are joined together and connected to the negative pole of the battery. It is clear that each condenser is charged up to the potential difference between the battery poles and therefore takes the same quantity of electricity as if it were used alone ($Q = CV$). If the condensers are alike the total quantity on the three will be three times the quantity which one would take, so that for the whole arrangement we have

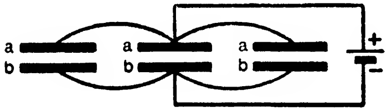


Fig. 44.

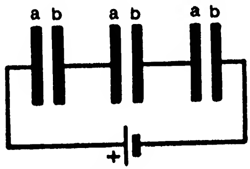


Fig. 45

three times the quantity of electricity that one would take and the potential difference between the plates is the same as one would have, viz. equal to the E.M.F. of the battery. Hence since the quantity is 3 times and the potential difference the same, the capacity of the three in parallel is three times the capacity of one of them (capacity = quantity ÷ potential).

Thus *if, say, three equal capacities are put in parallel the combined capacity is three times the capacity of one of them.* If, say, two capacities C_1 and C_2 are in parallel the combined capacity C is the sum of the separate capacities, *i.e.* $C = C_1 + C_2$. **Joining capacities in parallel increases the capacity in the circuit.** In this respect it *resembles joining resistances in series.*

Fig. 45 shows three condensers joined in *series* (*i.e.* the *b* plate of the first joined to the *a* plate of the second, the

b of this to the *a* of the next, and so on). Since the outflow from one condenser is the charge on the next the charge Q on the positive coating of each must be the same and equal to that given to the first condenser from the battery. If the potential difference on the whole arrangement be V, and V_1, V_2, and V_3 be the potential differences on the separate condensers, then $V = V_1 + V_2 + V_3$. Thus if C be the capacity of our series arrangement, C_1, C_2, and C_3, the separate capacities, we get—

$$V = V_1 + V_2 + V_3;$$

$$\therefore \frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3};$$

$$\therefore \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

Now this formula for condensers or capacities in series is like the formula for resistances in parallel. If the three capacities are equal, say, each C_1, then $1/C = 3/C_1$; $\therefore C = \frac{1}{3}C_1$. Thus *if, say, three equal capacities are put in series the combined capacity is one third the capacity of one of them.* **Joining capacities in series decreases the capacity in the circuit.** In this respect it *resembles joining resistances in parallel.*

To take an example, if two condensers of 3 and 6 microfarads capacity be put *in parallel* the total capacity is $3 + 6 = 9$ microfarads: if they be put *in series* the total capacity is 2 microfarads:—

$$\frac{1}{C} = \frac{1}{3} + \frac{1}{6} = \frac{6+3}{18} = \frac{9}{18}; \quad \therefore C = \frac{18}{9} = 2.$$

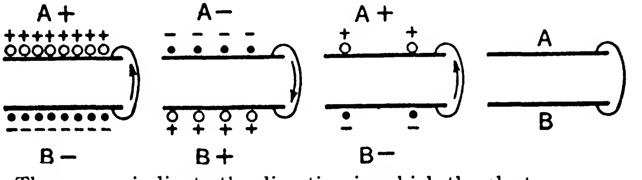
If two resistances of 3 and 6 ohms be *in parallel* the total resistance is 2 ohms: if they be *in series* the total resistance is 9 ohms.

Sometimes capacities are in series, sometimes in parallel in wireless receivers, just as resistances are, as you will see alter, and the above important points must be remembered.

4. Discharging a Condenser.

If the two plates of a charged condenser be connected by a wire a discharge takes place through the wire, and the potentials of the plates are equalised.

According to the electron theory, piled up on the positive plate A we have a number of positive ions, *i.e.* atoms each of which is deficient of one electron, whilst piled up on the negative plate B we have an equal number of electrons. On joining A and B by a wire the electrons " travel " (in the manner indicated in Chapter I.) along the wire from B to A, thus making up the deficit of electrons in the positive ions on A, and easing B of its surplus electrons: the potentials of the plates are equalised.



The arrows indicate the direction in which the electrons are about to travel.

Fig. 46.

Actually the discharge of a condenser is rarely such a simple matter as is outlined above. To fix ideas let us imagine that we start off with a charged condenser, having, let us say, 8 positive ions on A and 8 surplus negative electrons on B (A *is positively charged* and B *negatively charged*), and let A and B be now joined by a wire (Fig. 46). Electrons rush round from B to A, but if the resistance of the wire is not too large, so great is the rush that *more than* 8 electrons leave B. Suppose 12 electrons rush round from B to A. Clearly 8 of these will satisfy and neutralise the 8 positive ions on A, leaving A with a surplus of 4 electrons, *i.e.* A *is now negatively charged*; similarly B has four positive ions, the remains of the four atoms from which the four extra electrons cleared out, *i.e.* B is *now positively charged.*

Electrons now rush from A to B, but again so great is the rush that more than 4 electrons leave A. Suppose 6 electrons rush round from A to B. From the preceding it follows that A is left with 2 surplus positive ions, the remains of the two atoms from which the two extra electrons have been obtained, *i.e.* A *is again positively charged.* Similarly B has got two more electrons than it requires, *i.e.* B *is again negatively charged.*

The above actions are repeated, the rushes backwards and forwards getting less and less each time until they cease altogether, matters becoming quite normal with A and B at equal potentials. Fig. 46 pictures the results. Of course in practice it is not a matter of eight electrons and eight ions but of millions.

Such a discharge as is indicated above is called an **oscillatory discharge**, and discharges of this type are much in evidence in wireless. A rush from B to A is termed an **oscillation**, a double rush from B to A and back to B is termed a **vibration**, and the number of vibrations in one second is called the **frequency** of the oscillatory discharge. The **period** is the very short time taken to execute one *vibration.* You will readily understand that these are *high frequency* oscillations of electricity.

5. Condensers in Wireless.

A convenient type of condenser is constructed of alternate sheets of tinfoil (thin lines in Fig. 47) and paraffined paper or mica (thick lines), the odd conducting sheets being bunched together and connected to one terminal A, the even numbers being joined to terminal B; the arrangement is thus equivalent to two large plates separated by a thin and good dielectric. The small **fixed condensers** used in wireless are often constructed in this manner.

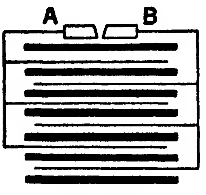


Fig. 47.

A **variable condenser**, as the name suggests, is one the capacity of which can be readily altered, and these are extensively used in wireless. The most common type

employs an air dielectric, the variable capacity being obtained by rotating one set of metal plates into and out of another fixed set of metal plates, the rotating plates being all metallically connected together and forming one coating of the condenser, the fixed plates being similarly connected and forming the other coating of the condenser.

In one type both sets of plates are semicircular in shape to obtain a uniform increase or decrease *of capacity* as the moving plates are rotated into or out of the fixed plates. It should be noted that the capacity is greatest when the moving plates are completely inside the fixed plates and least when they are outside the fixed plates. Usually a dial graduated in degrees, or a pointer moving over a scale, is attached to the spindle carrying the moving plates so that the amount of rotation in degrees can be noted. A given difference in dial reading represents a constant difference *in capacity* all round the dial, so that if a curve be plotted showing the connection between capacity and dial reading such a curve will be a straight line: hence the condenser is frequently referred to as a **straight-line capacity condenser.** The principle of such a condenser will be gathered from the plan of the plates shown in Fig. 48.

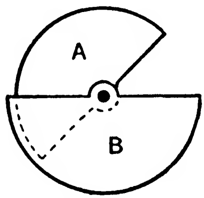


Fig. 48.

The above condenser, although still made and used, has been largely superseded by three other modified types in modern wireless receivers. To explain the principle of these, however, we must anticipate certain facts which are dealt with in Chapter VI.: you will probably have no difficulty in understanding them even at this stage.

We have said that condensers are used to "tune in" a receiver to a particular wave length sent out by a particular station which is required, and as will be seen presently *increasing the capacity tunes in to a longer wave and decreasing the capacity tunes in to a shorter wave.* (Incidentally "long waves" means that the frequency is *lower* and "short waves" means that the frequency is *higher*—see later.)

Wave length, however, is not directly proportional to capacity, but *it is proportional to the square root of the capacity*; thus if the capacity is increased four times the wave length to which the apparatus is tuned is not four times, but only twice what it was before, and if the capacity is increased sixteen times the wave length to which it is tuned is only four times what it was before. The result of this is that stations differing by a given wave length are crowded together at the bottom of the scale and widely separated at the top of the straight line capacity condenser.

Clearly, then, if we make a condenser with plates so shaped that *the capacity is proportional to the square of the number of degrees the moving plates turn*, the wave length will be proportional to the angle of rotation of the moving plates: in other words, if we were listening in to a station sending out a wave length of 250 metres and the tuning condenser was at 10°, and if we wished to get another station transmitting a 500 metre wave, it would only be necessary to rotate the condenser to about 20°. (We are making certain assumptions here but we need not worry you with them.) A condenser made in this way is called a *square law condenser*: if we plot the relation between rotation and wave length we get a straight line, and it is therefore often referred to as a **straight-line wave length** condenser. Fig. 49 gives roughly the "cam" shape, etc., of the moving plates of this condenser: this shape means that the capacity increases more rapidly towards the end than at the beginning of the scale.

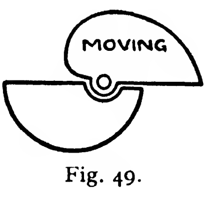


Fig. 49.

But broadcasting stations are separated from each other not by a constant difference in wave length but by a constant difference *in frequency*. This difference at present is 9000 cycles or 9 kilocycles (see " sidebands "—Chapter VI). Now let us see what the effect of this is, and to simplify matters we will assume the difference to be 10 kilocycles instead of 9 (there would be less " interference " between stations if it were).

A station with a wave length of 200 metres has a frequency of 1500 kilocycles (the wave length in metres multiplied by the frequency in kilocycles is always 300,000 —see Chapter VI.). A station with a wave length of 300 metres has a frequency of 1000 kilocycles. The difference in frequency is 500, and therefore between these stations, on the 10 kilocycle spacing, we could get in 49 stations. If a station had a wave length of 50 metres (6000 kilocycles) and another had a wave length of 150 metres (2000 kilocycles) the difference in frequency would be 4000 kilocycles, and therefore we could get in 399 stations. Thus on the shorter wave lengths a " wave band " of 100 metres may be accommodating nearly 400 stations, whereas on the longer waves the same wave band of 100 metres can accommodate only 50, say.

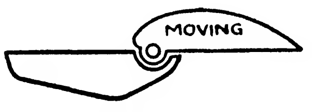


Fig. 50.

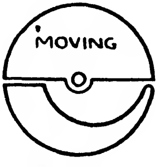


Fig. 51.

The square law condenser, then, when stations became separated by the definite frequency difference of 9 kilocycles, gave a certain crowding of stations at the bottom end of the tuning condenser dial, and so manufacturers turned out another type—the **straight-line frequency condenser**—in which the dial reading is proportional not to capacity or wave length but to frequency, so that they give *approximately* equal dial spacings of stations separated by equal frequencies (we say again approximately because other factors are to be taken into account). The general shape of the plates is shown in Fig. 50.

A drawback to the condenser of Fig. 50 is that it takes a lot of space when opened out: this has been partly remedied by altering the shape of the fixed plates so that the moving plates may be made more circular (Fig. 51).

Small stray capacities in the receiver sometimes upset readings a little in the lower part of the scale and there is a tendency for a little crowding in practice of stations at the top end. A typical condenser is shown in Fig. 52.

When the general public cried out for a single dial tuning, and "ganged condensers," *i.e.* condensers simultaneously

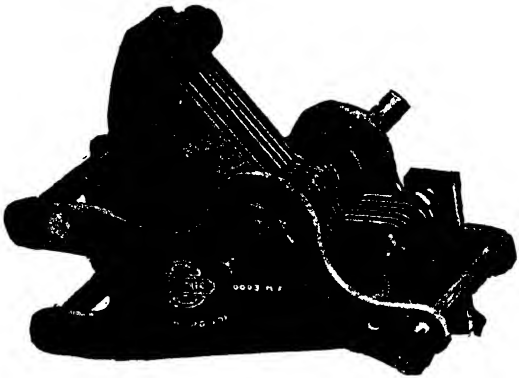


Fig. 52.

moved by one dial, were demanded, a condenser known as the **log mid-line condenser** came into use. It is a sort of "half-way house" between the other two: but the straight line frequency type is still a favourite.

In a **differential condenser** there are two sets of fixed plates, insulated from each other and connected to separate terminals, the moving plates (joined to another terminal) rotating out of one fixed set into the other. For very fine tuning in wireless receivers a small variable condenser known as a **vernier condenser** or a *trimmer* is often employed, joined across the main condenser.

An **electrolytic condenser** consists of a central rod of aluminium (one "plate") coated with a thin non-metallic film (dielectric) and surrounded by a special liquid or paste (which is the other "plate"), the whole being in a metal case which, of course, makes contact with the liquid or paste. The film is originally deposited by electrolysis, *i.e.* by passing a current through the liquid.

6. Induced Currents and Pressures.

You have already seen that an electric current in a circuit is always accompanied by a magnetic field: whenever you establish a current you establish a magnetic field, and when you cut off the current you cut off the magnetic field. Now in 1831 Faraday discovered what might be called the converse of this: he found that if he had a circuit, say a ring of copper wire, and he created, by any means, a magnetic field where the ring was, he created a current in the ring.

In fact he showed that: (1) when he started the magnetic field he got a *momentary* current in the ring, and then everything was quite steady again; (2) when he cut out the magnetic field he got another *momentary* current; (3) if, while the magnetic field was there, he increased the strength of the field he got another *momentary* current; and (4) if he decreased the strength of the field he got another *momentary* current. He got a current whenever he started, stopped, increased or decreased the magnetic field in the vicinity of the circuit (the ring of copper), the currents only lasting for a moment while the change in the field was taking place. Currents (and of course *pressures*) produced in this way are called **induced currents** (and *induced pressures*) and the effects are referred to as *electro-magnetic induction.*

7. Mutual Induction and Self-Induction.

We can now get down to a little more detail. In Fig. 53 imagine CD is a *coil* of wire joined to a battery and AB is another coil joined to a galvanometer (which is simply a coil of wire with a small magnet pivoted at the centre: the magnet will be deflected if a current passes and the direction of deflection will depend on which way the current passes). CD is referred to as the **primary** circuit and AB as the **secondary** circuit.

Now if a current be started in CD in the direction C to D, the galvanometer will be deflected for a moment showing that a momentary current has been induced in AB in the direction B to A, *i.e. opposite* to the primary current. Of

course starting a current in CD means that we are suddenly setting up a magnetic field, and some of the lines naturally reach the circuit AB. If we stop the current in CD we wipe out the magnetic field and the galvanometer will indicate that a momentary induced current is set up in AB in the direction A to B, *i.e.* in the *same* direction as the one which is being cut off.

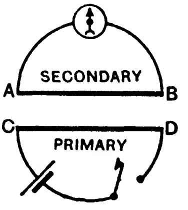


Fig. 53.

Similar results happen if the current in CD be increased or decreased: if we increase the current in CD the induced current in AB is from B to A, and if we decrease it, the induced current is from A to B. Further, not only does the primary act upon the secondary in this way but the secondary changes react upon the primary: hence these inductive effects between two circuits are referred to as **mutual induction.**

Notice this too—when we start the primary current from C to D the momentary secondary current flows from B to A: it therefore creates for a moment a field in the secondary *opposite in direction* to the field which the primary is putting there, *i.e.* the induced current has such a direction that it *opposes* the " change " which is causing it. Again, when the primary current and its field are cut off the induced secondary current is from A to B: it therefore creates for a moment a field in the *same direction* as the one which is being cut off, *i.e.* it opposes the "change" which is causing it. This you will find to be the case in all examples of electromagnetic induction, and Lenz, in 1834, stated it in what is called **Lenz's Law** as follows: " In every case the induced current is such that it tends to stop the change which causes it."

We have seen that the growth of a current in a wire means the growth of a magnetic field, also that an altering magnetic field near a conductor produces a current in the conductor; hence it is not surprising to find that this magnetic field which grows with the current *acts upon the*

current itself; that is, it induces a pressure or E.M.F. in the original conductor acting in such a way as to oppose the growth of the current. Hence, when we start a current in a wire, the current produces a magnetic field, this reacts upon the current by setting up an *opposing pressure* which delays its growth, the result being that it takes time to cause a current to reach its full value in the circuit. Similarly, when the current in a circuit is broken, the field is destroyed, and an induced current in the *same* direction as the one cut off is established. (In both cases note that the induced pressure or current opposes the change causing it.) Similar results take place when a current in a conductor increases or decreases in strength. These effects are known as **self-induction.**

We can examine the preceding in a little more detail. When a current is started in a circuit the magnetic field does not come into complete existence *immediately*. It seems to begin, as it were, inside the wire and gradually extend outwards, as shown in Fig. 54: at (*a*) the current has just started and the field is small, at (*b*) it has grown, at (*c*) it has grown still more, and so on, until finally it extends to a great distance.

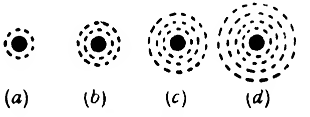


Fig. 54.

Now this field is being built up by energy taken from the current; hence the current grows gradually, not reaching its final value until the field is fully established, and this is equivalent to an *opposing pressure* being induced in the wire. Similarly, when the current is switched off the magnetic field gradually collapses into the wire, giving up its energy as it does so; thus the current does not immediately drop to zero, and the effect is equivalent to an *induced direct current*, *i.e.* one in the same direction as the current cut off.

When a body is at rest it tends to remain at rest, and when it is once in motion it tends to keep moving; this property is referred to as *inertia*, and it is evidently greater the

greater the weight of the body. Now from the preceding it will be clear that self-induction behaves in a circuit like *inertia, e.g.* when we try to produce a current in a circuit this self-induction or inertia tends to choke the current back, and when we try to stop the current this self-induction tries to make it keep on.

Of course if we have a permanent magnet and bring it near a coil of wire we will be changing the magnetic field in the vicinity of the coil, and again we will get an induced current in the coil. If we hold the magnet still and suitably move the coil in the magnetic field the same thing happens. And Lenz's law applies here also.

8. The Inductance of a Coil. The Henry and the Microhenry.

The general name for the property exhibited by conductors of electricity dealt with in Art. 7, *i.e.* the property of opposing the starting and stopping of a current or any change in the strength of a current, is **inductance.** In a straight wire the inductance is small; *it is much greater in a coil consisting of many turns, and it is considerably increased if the coil be wound upon an iron core:* in a *coil* each turn acts upon the other, and if *iron* is there it is magnetised so that the field is stronger.

The unit of *inductance* is the **henry**: *a coil has an inductance (self-inductance) of one henry if a current increasing at the rate of one ampere per second brings on an opposing pressure of one volt.* Similarly *two coils have an inductance (mutual inductance) of one henry if a current increasing in one at the rate of one ampere per second induces a pressure of one volt in the other.* We can write

$$\text{Henries} = \frac{\text{Volts}}{\text{Amperes per Second}}.$$

Inductances used in wireless are sometimes measured in **microhenries**: a microhenry is $\frac{1}{1000000}$ of a henry. Iron-core transformers used in wireless may have inductance values of several henries.

As in the case of condensers, inductance coils are largely used in wireless, *e.g.* for tuning in stations and for other

purposes. As you will see later increasing the inductance tunes to a longer wave (lower frequency) and decreasing it tunes to a shorter wave (higher frequency).

You should notice the *three properties* of every electric circuit, viz. **resistance, inductance,** and **capacity.** Inductance is only important when the current is changing, so that with a constant current circuit (except for a moment at starting and stopping) it does not enter much into the business: but with an alternating current in the circuit which is never steady, constantly rising, falling, reversing, rising, falling, and so on—constantly *changing* in fact—inductive effects will always be present, *i.e.* inductance plays an important part. Capacity, too, is important with alternating currents but not with continuous currents. In fact with alternating currents all three properties of the circuit must be taken into account, but with continuous currents we need only bother about the resistance.

9. Inductance Coils in Wireless. Tuning Coils.

There are many types of **inductance coils** used in wireless, each having certain features making it specially suited for the purpose in view. Modern receivers are often fitted with special coils, sometimes with rather complicated internal connections and tappings, the full purpose and action of which we cannot explain at this stage. In this section we will merely give a few simple cases to illustrate general principles, together with a few modern types to indicate their general appearance and construction: details of these modern types will be understood later when their application to modern receiving circuits is dealt with.

Only a few years ago experimenters largely made their own coils, and there was an advantage in this for it increased the interest in the subject, led to development and improvement, and was all for the good of " Radio " and its better understanding by the experimenter himself. Good coils can now be purchased cheaply, but we will deal with one or two of the " old soldiers " who will never die—they are handy for the experimenter even to-day.

The *tapped inductance coil* appears in many forms, and is shown in principle in Fig. 55. It consists of a coil or coils of insulated wire wound on a drum of suitable material—cardboard, ebonite, paxolin—and at intervals " tappings " are taken to terminals or studs. In the latter case connection to the studs is made by means of a rotating switch arm, as shown: thus if one end of a circuit be joined to the end of the coil on the left and the other end of the circuit be joined to the rotating arm, rotating the latter towards the right will increase the inductance in the circuit and rotating to the left will decrease the inductance. These tapped inductances in various forms, particularly with the tappings joined to connecting terminals, are widely used.

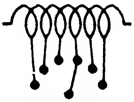


Fig. 55.

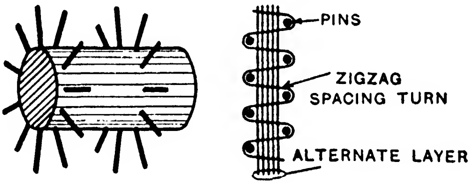


Fig. 56.

The *lattice inductance coil*, a friend of the old days, is still a convenient one. It is made by winding a zig-zag turn of insulated wire round a number of pegs in a former (Fig. 56). On the completion of this a single layer of wire is wound round the former, then another zig-zag turn, and so on. Finally the coil is slightly soaked in melted paraffin wax and the pins and former removed. A modification is shown in Fig. 57 (these windings were often referred to as *basket coil windings*). The " former " consists of an *odd* number of spokes—generally 9 or 11 or 13—radiating from a hub after the manner of one of the two radiating sets of

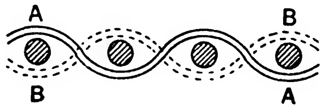


Fig. 57.

spokes of Fig. 56. In *single* basket winding the wire passes on alternate sides of the spokes, as shown in Fig. 57. In *double* basket winding the wire passes on one side of two spokes, then crosses over and passes on the other side

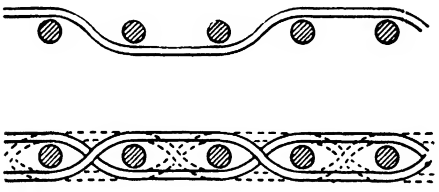


Fig. 58.

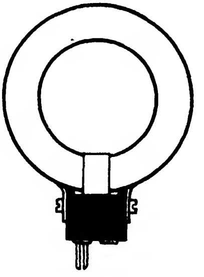


Fig. 59.

of the next two spokes, and so on (Fig. 58), the crossing points being alternate. You will come across other coil winding names in your reading, e.g. *honeycomb*, *duo-lateral*, etc., the former referring to a winding in which the turns of one layer are over the turns in the layer below,

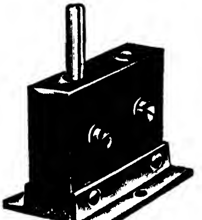


Fig. 60.

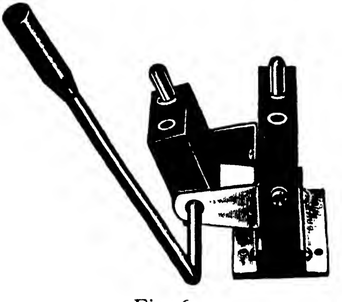


Fig. 61.

and the latter is one in which the turns of one layer are over the spaces between the turns in the layer below.

A practical form in which the simpler type of inductance coil is arranged and used is the *plug-in coil* shown in Fig. 59. The ends of the coil are brought to a plug and socket

mounted in a piece of ebonite attached to the coil: the receiving set is fitted with a corresponding plug and socket (Fig. 60), so that the coil can be plugged into the holder. A variable coupling—utilising the principle of mutual induction—can be used with two plug-in coils and some form of holder similar to Fig 61. The holder carries two coils (a primary and a secondary), and one is pivoted so that the distance between the coils can be varied: the nearer the coils are together the greater is the inductance. Another type of holder was arranged to take three coils, a fixed one with a movable one at each side: such a holder and three coils was often used in receiving sets. A coil similar to that of Fig. 59, but with three taps so that different inductances can be used, is shown in Fig. 62: similar "plug-in" coils with one or two taps (generally called X coils) can also be obtained. Plug-in coils are numbered by the makers to indicate their suitability for different wave lengths.

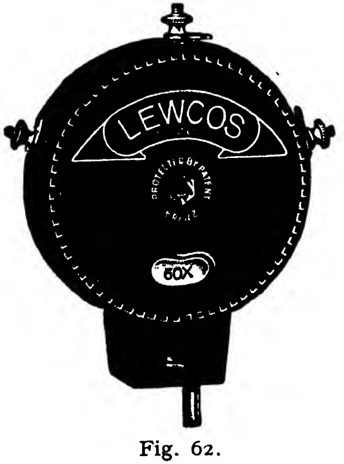


Fig. 62.

Modern coils *appear* rather complex with their tappings and connections, for by a switching arrangement they are often made suitable for "medium" waves (the "broadcasting band" of wave lengths, viz. 200-550 metres), or for "long" waves (550 upwards), and are therefore **dual range coils**: they switch in more inductance when the long waves are wanted. In some they are also arranged for short-waves (say 13-150 m.). Moreover, a receiver generally requires a coil called a *reaction coil*, and this is often included in the modern coil. Further, the coils are sometimes arranged for other uses besides tuning.

Thus Fig. 63, for example, shows the general appearance of a modern high grade coil—the *Lewcos DWA coil*—and Fig. 64 gives diagrammatically the principle of the various internal tappings when the coil is used as a tuning coil for an aerial: you will understand this figure later. The rod shown manipulates the switches incorporated: if the rod is *in*, the coil is suitable for the long waves, and if out, for the medium waves. Fig. 65 shows diagrammatically the coils, tappings, etc., of another Lewcos coil provided with six terminals. But both of these you will understand later.

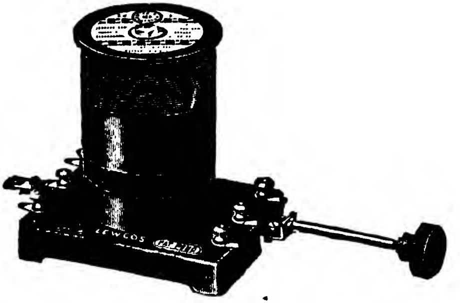


Fig. 63.

The general principle of the modern dual range coil will be better understood from the diagrammatic sketch of a good home-made one shown in Fig. 66. Here S is the *medium wave coil* (we often say "short" instead of "medium") consisting of about 60 turns of 30 gauge enamelled wire wound on a tube of paxolin of about 2 inches diameter: L is the *long wave coil* of 250-300 turns; S.R. is the *medium wave reaction coil* of 35-40 turns; and LR the long *wave reaction coil* of about 70 turns. You will read about the use of these reaction coils later. For simplicity the four coils are shown in line in Fig. 66, but in the actual case

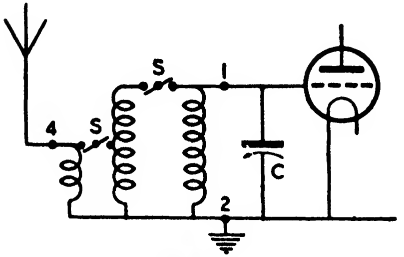


Fig. 64.

L and LR are wound on one former, a space of about one inch being left between the end of one and the beginning of the next. S and SR are wound on another and the two sets fixed at right angles. The connections between the coils and tappings to terminals and switch P are as shown.

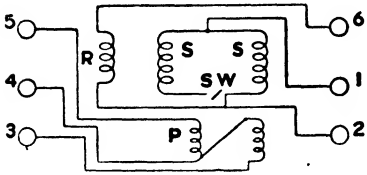


Fig. 65.

The switch is a " plunger," *i.e.* when it is pulled out the contacts *x*, *y*, and plunger are joined. Thus when the

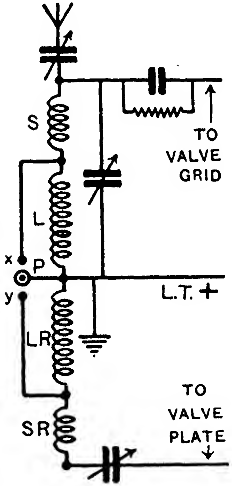


Fig. 66.

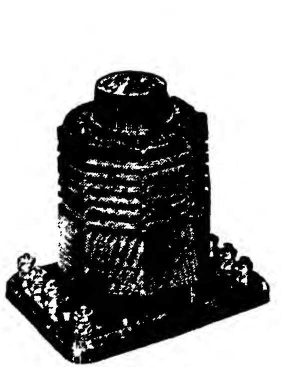


Fig. 67.

switch is " out " the coils L and LR are short circuited *via* the switch, and the coil is adapted for medium waves. When P is " in " the arrangement is as shown, L and LR are in circuit and the tuner is adapted for long waves.

Fig. 67 shows the *Telsen Dual Range Aerial Coil*, the changes being carried out by means of a three point switch.

As above, a reaction winding is included. Another Telsen coil—the *Screened Dual Range Tuning Coil*—is shown in Fig. 68, which is largely used both as an aerial tuner (medium and long waves) or as a coupling device between valves. The coil is shielded or "screened" by an aluminium can: Fig. 69 gives the coils and tappings.

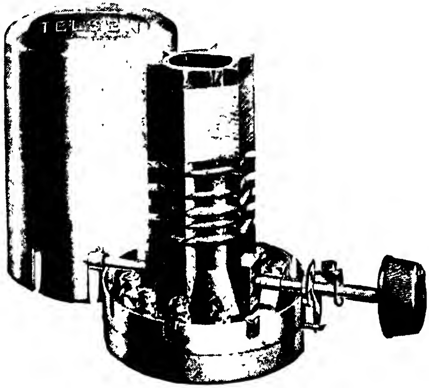


Fig. 68.

The preceding coils have air cores. An iron core would increase the inductance, but as high-frequency currents pass in the coils, currents would be *induced* in the iron and much energy would be lost due to these core currents (see

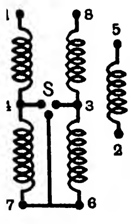


Fig. 69.

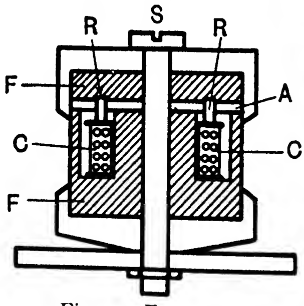


Fig. 70. Ferrocart.

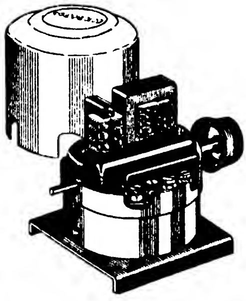


Fig. 70*a*. Colvern Ferrocart.

"eddy current" and "hysteresis" losses—p. 95). Recently cores of fine particles of iron have been introduced *to give large inductance with small coils* (there is less wire and fewer turns because the iron increases the inductance),

the construction being such that the "iron losses" are almost eliminated. There are several forms of these **Ferrocart Coils,** as they are called, the general principle being a mixture of fine iron particles and insulating material in thin layers separated by thin intermediate insulating layers. A simple type which the beginner will readily understand is shown in Fig. 70. C is the coil enclosed in F, the Ferrocart material. By the screw S the Ferrocart cover is brought to or from the core F (by compressing, etc., the rubber ring R), thus varying the air-gap A and varying the inductance. Many manufacturers are making these iron-core coils, using their own core material and "trade name" and designing them to suit modern receiver conditions. Since the inductance can be so readily varied by altering the position of the core it is possible that sets of the future may be mainly "tuned" in this way. The system is called "permeability tuning."

10. Headphones, Microphones, and Loud Speakers.

The Bell magneto telephone, as it is called, was originally used both as a sound *receiver* corresponding to the **headphones** and *loud speaker,* and as a sound *transmitter* corresponding to the *microphone* now used in broadcasting studios. A section through the instrument is shown in Fig. 71. Here M is a permanent magnet carrying at one end a piece of soft iron S. This forms the core for a coil C which has leads to the two terminals of the instrument. In front of S is fixed a thin, soft iron disc DD. The case is of ebonite.

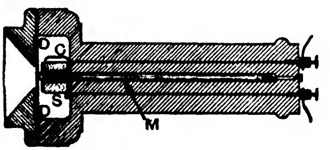


Fig. 71.

The action is as follows: When a person speaks into the instrument the sound waves cause the disc to vibrate, and as it moves to and from the soft iron core the distribution of the magnetic lines of force in the vicinity of the coil is altered. A current is, therefore, induced in C, and this current changes according to the way the lines of force

passing through C changes, *i.e.* according to the vibrations of the disc and therefore according to the words spoken.

At the far end of the circuit is a similar instrument to act as a receiver, the terminals of which are directly connected to those at the transmitter, so that as the currents generated in C vary with the sound, so also do those received at the distant receiver.

The reverse operation now takes place at the receiver. The current in its coils varying, the field in the neighbourhood varies, and the soft iron piece of the receiver attracts with varying strengths the vibrating disc immediately in front of it. Thus the disc of the receiver copies the movements of the disc of the transmitter, and these movements of the receiving disc being transferred to the air, the sound also is reproduced.

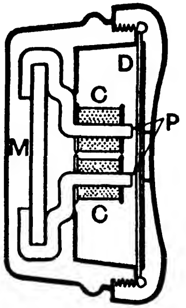


Fig. 72.

From the above it will be seen that two of these instruments without any battery can be used as a simple telephone circuit.

In modern practice the Bell telephone is used only as a receiver (*e.g.* the headphones) and Fig. 72 depicts the construction of one present type of instrument. M is the permanent cobalt-steel magnet; as a rule it is in the form of a ring and is fitted with soft iron pole pieces P on which the coils C are wound. D is a stalloy disc. The containing case is of ebonite or some special composition. The wires leading from the coils to the terminals are not shown in the figure.

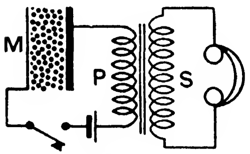


Fig. 73.

The **microphone** is, of course, used at the sending end. The general *principle* of the modern carbon microphone transmitter is shown in Fig. 73. A number of granules of carbon are enclosed in a chamber between two suitable

plates. The latter are joined through a key and battery to a primary coil P, and the secondary coil S is joined to the outside circuit which contains the receiver—say the telephones.

Suppose the key is closed and a steady (small) current is flowing from the battery. When a person speaks in front of the diaphragm M the latter vibrates according to the sound waves. This produces compressions and decompressions of the granules. When they are pressed together the resistance is less and a greater current flows: when they are slacked the resistance is greater and less current flows. This varying current, depending on the words spoken, passes through P and produces by induction a corresponding varying current in S which passes through the telephone receiver and the latter reproduces the sound.

The **Reisz microphone** employs a thin layer of powdered carbon spread on a slab of marble and covered by a rubber sheet which takes the place of the diaphragm above. It works on the same principle, but does not tend to strengthen some notes at the expense of others as the granule instrument does.

The **magnetophone** is another type of microphone working on a different principle. It consists of a small coil of wire on the back of a freely moving plate. The coil is in the magnetic field between the poles of a magnet. The sound waves cause the plate and coil to move, and varying currents are induced in the coil. This is largely used in present-day broadcasting.

In all cases you will note that we get a varying current depending on the words spoken: what is really done with this varying current you will see in Chapter VI.

For many years the **loud speaker** has been the " bad boy " of the Radio School. We started off in the early days with the old "horn" type, and we marvelled so much at the wonders of getting anything at all that we paid little attention to the *quality* of what we did get. And our ears got so attuned to the throaty reproduction that even when the cone type of speaker arrived bringing with

it the higher range, many listeners declared them shrill and harsh and settled down again to their old speakers: they wanted *bass* and plenty of it.

Then, later, and almost suddenly, the cry went out for better quality, more faithful reproduction, better loud speakers, and the designers and manufacturers responded, with the result that there are some really excellent types on the market to-day. But nevertheless there are many people using speakers even to-day which, if the ear were as critical as the eye, would disappear into the dust-bin to-morrow.

But it is well to mention that even a good speaker cannot do much if the receiver is not efficient, and even if the receiver also is good the speaker will not work well unless it is "matched" to the output valve in the set: this matching is important and is dealt with in Chapter XI.

A full treatment of loud speakers cannot be given here for it is outside the purpose of this book, but speaking generally there are three main types: the *balanced armature cone* type, the *moving coil* type, and the *inductor dynamic* type, and they all depend on principles already dealt with.

Fig. 74 (*a*) shows the principle of the balanced armature. The iron armature is pivoted at the centre between the pole pieces of the magnets arranged as shown, and is in connection with the apex of a cone of paper or other suitable material. The magnets are fitted with coils which carry the varying current delivered by the output stage of the receiving set. This varying current depends of course on the words or music at the transmitting station. The iron armature is therefore attracted by amounts varying according to the current variations, and this movement is communicated *via* the cone to the air so that the sounds are reproduced.

The drawbacks to this type are mainly due to disturbing effects caused by the varying air gap, which we need not explain. This defect is greater if the armature is merely pivoted at one end, the other end moving between two poles (as is the case with some moving iron types): the balanced armature largely overcomes this as both ends of the

armature are affected (the figure is diagrammatic only). Some spring arrangement or its equivalent is used to stop the armature crashing on to the poles. This type of speaker is still largely used, but it is hardly suitable with pentode output valves unless used with what is called a choke and tone corrector dealt with in Chapter XI.

The moving coil speaker is the best if it is properly matched to the output valve of the set, for under these conditions it has no equal for quality of reproduction. As the name suggests the moving part is a small coil carrying the varying current, and this coil is in the magnetic field of a magnet just as the armature is in the preceding. The varying current in the coil in the magnetic field causes a varying movement of the coil which is communicated to the air as above and the sounds reproduced. The usual method is to have a primary coil in the output circuit of the last valve and to feed the moving coil from a secondary—in other words output *transformers* (Chapter V.) are used with these speakers. Further, in one type the magnet producing the field is a permanent magnet —hence the name you will often see, viz. *permanent magnet moving coil speaker*; in the other type current is taken from the mains to magnetise the iron pole-pieces. The latter

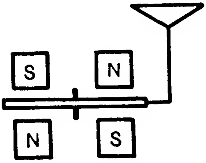
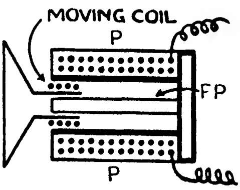


Fig. 74 (*a*).



P = Pot. PP = Pole Piece.

Fig. 74 (*b*).

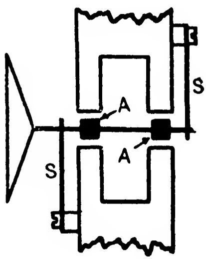


Fig. 74 (*c*).

type is better if it can be used, but excellent makes of the former are on the market. The construction and action will be gathered from Fig. 74 (*b*): this figure is, of course, only diagrammatic to show the principle.

The inductor dynamic is a speaker which comes, as it were, as a medium between the balanced armature and moving coil types, but few firms have taken up their manufacture, although many listeners class them as equal to the moving coil. There are four pole-pieces and two armatures (A in Fig. 74 (*c*)). The two armatures are held together by a light rod and attached to two springs S at opposite ends as shown. Thus when the armature is drawn to either side by the output currents passing, it travels horizontally, *i.e.* the movement is a kind of push-pull, piston movement which is the ideal movement to be communicated to the cone. In this respect it is a very near approach to the coil movement in Fig. 74 (*b*), which is a true push-pull: thus the reproduction of the inductor dynamic is a near approach to that of the moving coil.

It is impossible to give definite advice to the beginner on the choice of a speaker, for much depends on the receiver and type of valves in use. The best way, perhaps, is to try the different makes and decide on the one which suits your own particular musical taste and requirements.

The moving coil, properly used, is an excellent speaker —*the* best—but there are some cheap ones which are far from perfect. Moreover, if your set is one of the older type with little power output and few of the devices for selectivity and quality, the substitution of a *good* moving coil speaker will lead to disappointment—a balanced armature type may be much more satisfactory under the circumstances.

But to those with a fairly modern receiver, or who intend to possess one, the moving coil can be recommended, and there are several good ones on the market at reasonable prices. For the benefit of the beginner we may briefly refer to one or two. The P.P.M. 19 of Messrs. Celestion —a permanent magnet moving-coil speaker—has a magnet of specially aged cobalt-steel of massive construction.

For " matching " to the output valve of the receiver it is fitted with a transformer (Chapter V., Art. 5). By means of this, four different connections can be made, thus matching the speaker to any of the chief types of output valves—mains, pentode, super-power, or power valve (Chapter VIII.). Its performance is excellent. The bass is good and clear without boom and the middle and upper ranges are very clear. It is also remarkably good in its power-handling capacity. Another excellent permanent magnet moving-coil speaker at a reasonable price is the Blue Spot 99 P.M.. This has a heavy magnet forged from high-grade magnet-steel (containing a high percentage of cobalt) which produces a strong magnetic field in the air-gap. A cover is fitted to the magnet to exclude dust and magnetic particles which might otherwise be attracted into the air-gap—an important feature. A specially-designed transformer is fitted for matching with power, super-power, or pentode output valves. The performance of the speaker is of a very high standard. It gave, on test with various commercial receivers and experimental circuits, very fine response curves, maintaining a good balance throughout the whole musical range.

There are some *dual speakers* on the market. These consist of two separate but matched speakers on the one chassis, one specially designed to cope with the higher notes and the other with the lower notes. This would seem to be an ideal arrangement, and it will probably be extensively incorporated in wireless receivers of the future.

An *electrostatic speaker* is obtainable which has neither coils nor magnets. It consists of two fairly large metal plates facing each other and constituting the plates of a condenser. These are joined to the output circuit of the receiver: the varying output produces a varying attraction between the plates which gives rise to the sound waves. The speaker is particularly good with high notes and " transients " (explosive sounds). If this be used in conjunction with a moving-coil speaker with its splendid bass and middle, the result is amazingly good.

The growing popularity of " Radio in the Car " has

recently led to the introduction of several "Midget" speakers. Small speakers can handle high notes, but "bass" requires larger cones, etc. Hence modifications in details have been necessary to produce these small speakers to cope with the whole musical range, but the general principles are still the same as those already explained. Further moving-coil speakers are now on the market fitted with an attachment for "Class B amplification" which, comparatively recently, came to the front in receiver design: this will be dealt with later, but the general principle and action of the speaker itself is again the same as already explained.

High notes travel in a beam along the axis of the speaker: therefore sit opposite, with your head catching this beam. Walls and furniture absorb or reflect sound according to their nature. Don't use the top of the speaker for framed "family photographs" and famous vases: they may cause "rattle" on some notes. Don't disconnect a speaker while the set is "on": you may get a high induced voltage which will damage it and the valve.

11. Baffles.

We have seen that when a speaker is producing sound, the cone attached, say to the moving coil, moves backwards and forwards, producing the sound waves. For a note of frequency 80 the cone moves forward 80 times and backward 80 times per second, and similar remarks apply to the notes of other frequencies. Every time the cone moves forward the air in front is compressed and that behind is rarefied. These differences in air pressure in front and behind tend immediately to equalise each other, *i.e.* the compressed air in front tends to move round the edge of the cone to the back, thus interfering with the free movement of the cone and spoiling the reproduction. In order to combat this fault it is necessary to provide something which will increase the distance from front to back thus giving a longer path of air—a path sufficiently long to prevent the air getting behind in time to interfere with the vibration whatever the frequency of the note.

Experiments and calculations have shown that the following distances are required:—

Frequency of Musical Note	Length of Air Path
30 cycles	9 ft.
60 ,,	4½ ft.
100 ,,	2¾ ft.
200 ,,	1½ ft.
1000 ,,	3¼ in.
Higher	Less

It will be noted that for the higher notes the distance is less. At 1000 cycles per second the distance is only 3¼ inches, and the cone of the speaker itself is sufficient for this. But for the lower notes the distance is much greater. Hence it is that a loud speaker must be firmly fixed at the front to a board or *baffle* to prevent the air from the front circulating to the back in such a way as to spoil the notes of lower frequency, *e.g.* the bass. It may be taken that the minimum size of a baffle should be about 30 inches square, the hole for the speaker being in the centre. (See Fig. 74*d*.)

But this is scarcely a neat piece of "furniture" and "feminine influence" is dead against it: hence manufacturers often fit the speaker in a cabinet, the front and sides of which taken together make up the necessary length of path. The use of such a cabinet sometimes leads, however, to further troubles, especially if the cabinet is closed at the back. It "colours" the speech and music due to box resonance, and produces an unpleasant boominess in the low notes. By this box resonance and boom the reproduction even from the most efficient set and speaker can be dreadfully marred.

This difficulty can, however, be largely overcome by lagging the inside of the cabinet with a material such as felt or wool. The principle has been applied in the

Howe Box Baffle installed in Broadcasting House and manufactured by McNeil and Co. under licence of the B.B.C. (Fig. 74*d*). One model consists of a box 18" × 18" × 12", the back being open and the front containing the circular aperture for the speaker. Inside, the sides, top, and bottom are thickly upholstered, the packing consisting of a

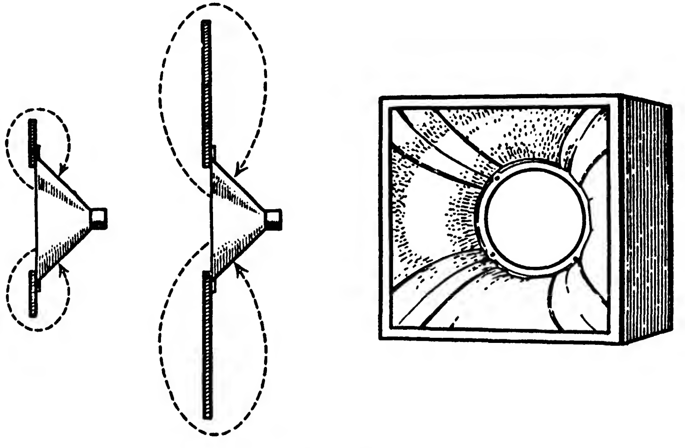


Fig. 74*d*.

specially-prepared silicate of cotton known as slagbestos, a material of good sound absorbing properties. Two other sizes, one larger, the other smaller, are available. We have personally tested this baffle, using two identical speakers one in the box baffle and the other, first in a cabinet of the ordinary type, and then on a baffle board 30" × 28". Comparing the results, the superiority of the box baffle was *decidedly pronounced:* a well-balanced, pleasant and natural reproduction was obtained throughout, free from any box resonance and boom.

CHAPTER V.

MORE FACTS ABOUT ALTERNATING CURRENTS: IMPEDANCE, CHOKES, TRANSFORMERS.

1. Further Facts about Alternating Currents.

Before proceeding with this chapter you should again read Art. 7 of Chapter I. The subject of alternating currents always presents some difficulty to beginners, but at this stage it is only necessary to draw attention to one or two elementary principles and one or two essential terms which you will encounter in your reading.

As already explained an alternating current is one which rises to a maximum, dies down to zero, reverses, rises to a maximum in the opposite direction, dies down to zero, reverses into the first direction, and so on.

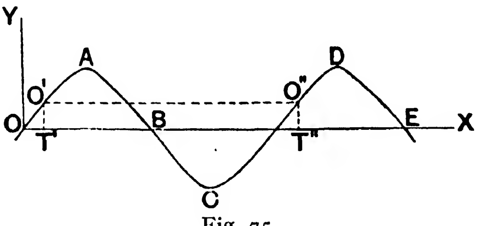


Fig. 75.

When an alternating current is produced in a circuit the E.M.F. or pressure continuously changes; it rises to a maximum, then dies away to zero, being followed immediately by a reversed E.M.F., which also rises to a maximum and dies away to zero, and so on. If, now, at any particular moment the E.M.F. is at a certain value, and is just going to commence a certain set of variations, then the time which elapses between this instant and the instant when the E.M.F. has the same value and is going

to commence an identical set of variations, is called the *period* of the E.M.F., and the number of periods accomplished in one second is called the **frequency**, the maximum value of the E.M.F. being called the *amplitude*. These names have already been explained and their exact meaning can best be seen from Fig. 75.

Suppose time is measured along OX, and E.M.F. along OY. Then for a certain alternating current the curve showing the relation between the variation of voltage and time will be OABCDE. . . . Volts measured above OX correspond to the direct E.M.F.; volts measured below OX correspond to the reversed E.M.F. We may select any arbitrary point on the curve, such as O′; then, counting time from the instant when the E.M.F. was last zero, we see that at time OT′, the voltage was O′T′. Drawing O′ O″ parallel to OX, we also see that at time OT″ the voltage was O″T″ = O′T′, and since when the voltage was O′T′ and O″T″ the same set of variations was commencing, we see that T′T″ represents the *period*. Evidently the period would also be represented by BE. The *frequency* would then be the number of such time intervals as T′T″ contained in one second, and the volts corresponding to the maximum points A, C, and D, etc., would be the *amplitude*. From O to B is referred to as an *alternation*, and from B to E as a **cycle.**

When the frequency reaches 100,000 cycles per second and more the alternating current is usually spoken of as a *high frequency oscillatory current* or a high frequency electrical oscillation. In wireless we really apply alternating current to the transmitting aerial in order to radiate energy which passes out through space in the form of aether waves—wireless waves—and for this to take place *very high frequency oscillatory current* is essential: in practice this frequency may be of the order one million cycles per second or more.

2. Lagging and Leading Currents.

When an alternating pressure (and current) exists in a circuit the frequency of the pressure and current are, of

course, the same, as you would naturally expect, but there is, however, this important difference. The alternating current does not always keep *in step* with the alternating pressure so that the maximum current does not always occur at the precise instant that the maximum pressure occurs: the maximum current sometimes occurs after and sometimes before the pressure has got to its maximum, and this depends on the kind of circuit the current is flowing in.

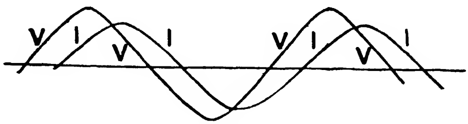


Fig. 76.

If there is much *inductance* in the circuit the maximum current occurs *after* the E.M.F. has reached its maximum and the current is then said to **lag.** On the other hand, if there is much *capacity* the maximum current occurs *before* the E.M.F. reaches its maximum and the current is then said to **lead.** Thus Fig. 76 shows a curve of alternating pressure V, V, V . . . and the curve of the accompanying current I, I, I, . . . in a circuit containing inductance, and you will see that the current lags behind the pressure.

The lag (and lead) are best expressed in terms of the period of the alternating current and pressure. Thus if the maximum current occurred $\frac{1}{8}$ period after the maximum pressure, we would say that the lag was $\frac{1}{8}$ of a period. If the frequency were 50 cycles per second the lag would also be said to be $\frac{1}{8}$ of $\frac{1}{50}$, *i.e.* $\frac{1}{400}$ second. Taking a complete cycle as 360°, then the lag could also be expressed as $\frac{1}{8}$ of 360°, *i.e.* 45°.

The lag and lead are sometimes spoken of as the **phase difference.** It is possible so to adjust the capacity (which causes lead) and the inductance (which causes lag) in an alternating current circuit that there is neither lag nor lead, and this is an important case in wireless circuits: in such a case we say that the current is *in phase* with the pressure.

3. "Flow" of Alternating Current "through" a Condenser.

In wireless and in alternating current work in general you will often come across the statement "a continuous current will not flow through a condenser, but an alternating current will": in fact in valve receiving sets condensers are used to prevent the flow of continuous current in certain paths, whilst permitting alternating current to "flow" in these same paths. It is essential that you should understand the exact meaning of such a statement.

Imagine a condenser joined to a battery which of course gives a continuous current. There is certainly a momentary flow of electrons from the negative pole of the battery to the condenser plate joined to it until the two are at the same potential, and a similar flow of electrons from the other condenser plate (leaving it with an excess of positive ions) to the positive pole of the battery until their potentials are the same. The condenser is charged, but there the matter ends; the dielectric of the condenser is an insulator and breaks the continuity of the circuit, so that nothing further happens unless the dielectric is ruptured. All this will be apparent from what has been said in Chapter IV.

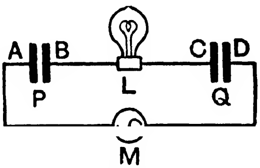


Fig. 77.

Now consider, for convenience, the alternating current circuit shown in Fig. 77 where P and Q are two condensers, L a lamp, and M an alternator (a machine or generator for producing alternating current). During the first half cycle of the alternating current, electrons rush, say, from M to A (making A negatively charged), an equal number rush from B to C (making B positive and C negative) and an equal number rush from D to M (making D positive). During this half cycle, therefore, there has been a flow of electrons through the lamp from B to C. Clearly, during the next half cycle the flow of electrons will again occur, but in the opposite direction, viz. M to D, C to B, and A to M: during this half cycle, therefore, there has been a flow of electrons through the lamp from C to B.

Thus although there is not a conducting road right round the whole circuit, the movement of electrons (*i.e.* the flow of current) to and fro in the alternator part of the circuit causes a corresponding movement of electrons (*i.e.* flow of current) to and fro in the part BC, and the lamp lights up. In a word the condensers do not stop the "action" or the "effect" of the alternating current in the part BC; hence the statement that an alternating current can flow through a condenser. It is a loose but brief and convenient way of stating what happens.

4. The Choking or Throttling Effect of an Inductance on an Alternating Current.

In wireless and in alternating current work in general you will also frequently come across the statement "an alternating current encounters considerably more opposition in flowing through a *coil* of wire, especially if wound on an iron core, than a continuous current does." In fact in all branches of electrical engineering it is customary to employ coils for the special purpose of preventing or choking back the flow of alternating current in some particular part of a circuit. Such coils are so made as to have a *big inductance* and generally they have a *low resistance* so as not to interfere with the flow of continuous current: they are called **choke coils** or **chokes.**

The whole action of the choke coil depends of course on self-induction. Imagine a coil consisting of a few turns of thick wire wound on an iron core: its resistance will be very small but its self-induction may be large. If a continuous current be started through the coil the induced opposing E.M.F. in the coil will certainly delay its growth, but when the current has once reached its full strength the inductive effect ceases, and owing to the small resistance, a large current will be flowing. If an alternating current be sent through the coil, however, the inductive effect is for ever acting, opposing the growth of the current and also opposing the decay and reversal: the coil continually exerts an opposition effect on the changing current.

In short, we might say that in the path of a rapidly altering current a choke coil acts like a very high resistance, while to a continuous current the resistance is practically negligible. This is because in the first case the inductive action is all important, while in the second case the inductive action scarcely matters at all.

And here you should recall for a moment all we have told you about *resistance* and *inductance*. The resistance of a wire is a property which depends essentially on the material, on its atomic and molecular condition, on whether it readily allows electrons to flow along it or not. The inductance of the wire, however, is closely associated with the magnetic field which is brought into existence when the current starts and *changes* when the current changes. You can have a wire, say, with only a small resistance, but you can so coil it and arrange matters that it has a big inductance. Remember inductance only becomes important when *changes* are taking place, and changes are always taking place in alternating current work.

Fig. 78.

Chokes are largely used in wireless. They are classed as *low frequency* (*L.F.*) *chokes* with cores of iron or magnetic alloy, and *high frequency* (*H.F.*) *chokes* with air cores. A tapped L.F. choke is shown in Fig. 78. Following the success of the "iron-dust core" tuning coil we already have iron-dust core H.F. chokes on the market.

5. Transformers.

A **transformer** is a device in which the inductive action of one circuit on another is employed in practice. Whilst chokes therefore make use of the property of *self-induction*, transformers act on the principle of *mutual induction*.

Commercial transformers consist of two coils—a primary AA (Fig. 79) and a secondary BB—quite separate from

each other and invariably wound upon an iron core, so as to increase the magnetic lines and the inductive effect. They are intended to work with alternating or varying currents, so that as the primary current is constantly varying inductive effects on the secondary are always occurring. The varying current in the primary produces a varying magnetisation of the iron core and varying magnetic lines in the secondary, which results in varying induced pressures in the secondary. The induced pressure in the secondary also depends on the number of turns of wire in it, and in fact we practically have the relation:—

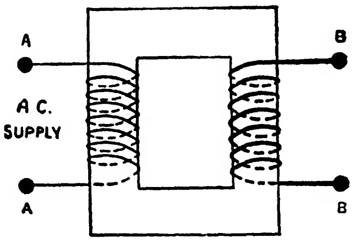


Fig. 79.

$$\frac{\text{Pressure in secondary}}{\text{Pressure in primary}} = \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}.$$

Thus if the secondary has 10 times the number of turns that the primary has, the pressure induced in the secondary is roughly ten times the pressure applied to the primary, *i.e.* the ratio of transformation is roughly 10 : 1. This is, of course, neglecting all losses of energy in the transformer. Further, since we cannot gain energy by the transformation, it follows that the current in the secondary must be proportionally less, *i.e.* (approximately).

$$\frac{\text{Current in secondary}}{\text{Current in primary}} = \frac{\text{Number of turns in primary}}{\text{Number of turns in secondary}}.$$

Transformers are used commercially (and in wireless) in two ways, viz.:—

(1) *Step-up Transformers.*—In these the alternating current in the primary induces alternating current in the secondary at a higher pressure, i.e. *they raise the pressure, and for this the secondary has more turns than the primary.*

(2) *Step-down Transformers.*—In these the alternating current in the primary induces alternating current in the secondary at a less pressure, i.e. *they lower the pressure, and for this the secondary has fewer turns than the primary.*

The above is only an elementary statement of transformer theory, and a more rigid treatment is beyond the scope of this book—and you really do not require it. But it may be noted that some of the "losses" which must be taken into account in giving exact expressions for the transformer are as follows:—

(*a*) The losses owing to some energy being spent in heating the coils when the currents flow.

(*b*) The losses due to *magnetic leakage, i.e.* due to the fact that all the lines of force due to the primary do not pass through the secondary circuit.

(*c*) The losses due to what are called *eddy currents* and *hysteresis* in the iron core.

The alternating primary current not only acts inductively on the secondary circuit but it also acts inductively on the iron core, setting up currents in it; these are known as eddy currents or Foucault currents, and they mean a waste of energy. To reduce them the core must be subdivided *laterally* (*e.g.* built up of a bundle of thin plates or fine iron wire), for this is the direction in which these currents tend to flow. The magnetic lines due to the primary current run *longitudinally*, so that the iron is, as it must be, still continuous in this direction. A core subdivided in this way is called a *laminated* core.

Now consider a bar of iron in a solenoid through which a current is passing; the bar is therefore magnetised. If the current be gradually reduced to zero the magnetism decreases, but when the current is zero some magnetism still remains, and it requires a certain current in the opposite direction (which of course tends to magnetise in the opposite direction) to wipe out the magnetism. In fact the changes in magnetism lag behind the changes in current. This becomes pronounced if the current be

alternating and is referred to as *hysteresis* (lag behind). It really represents a loss of energy caused by the changing magnetic condition, and the loss is big if the frequency be high.

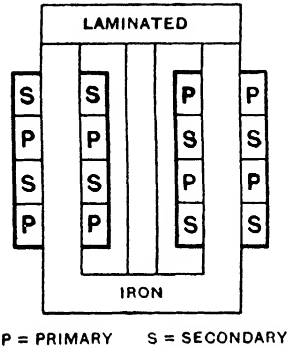


Fig. 80.

The principle of the construction of one form of modern *closed magnetic circuit transformers* will be gathered from Fig. 80. In older types, the iron core did not pass completely round to form a closed iron circuit for the magnetic lines: such were called *open magnetic circuit transformers.* The principle of what is called an **auto-transformer** is shown in Fig. 81. The "primary" winding is mounted on a laminated iron core, but instead of a separate secondary coil, a portion of the turns is tapped off to form the "secondary" circuit. In this way a secondary pressure is obtained lower than the primary pressure, practically in the ratio of the number of turns tapped off to the total number in the winding.

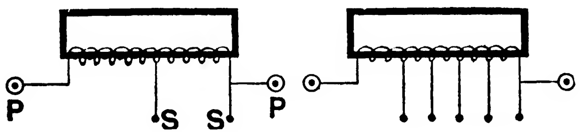


Fig. 81.

In wireless you will come across two types of transformers, one used for high frequency work and referred to as a *high frequency* (*H.F.*) *transformer*, the other used for lower frequency work and referred to as a *low frequency* (*L.F.*) *transformer*, a difference between them being that *low frequency transformers are provided with iron or some magnetic alloy cores but the usual H.F. types have air cores.* Every transformer with an iron core experiences a waste

of energy due to eddy currents and hysteresis, and this waste increases with the frequency: hence air core H.F. transformers are used, for air shows neither hysteresis nor eddy currents. The "iron-dust core" has, however, a promising future here also—for valve coupling.

A typical low frequency transformer is shown in Fig. 82: high frequency transformers often consist merely of two adjacent coils—quite separate—wound on a former. Some coils can be used both for "tuning" and as H.F. transformers.

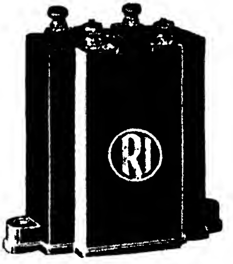


Fig. 82.

6. Measuring Alternating Currents and Pressures.

Since an alternating current is constantly changing and reversing, it cannot be measured by the decomposition of a solution of silver nitrate or by the deflection of a compass needle as can be done with a continuous current, for the effect of the current when it is flowing one way would be undone by the effect when it is flowing the other way. As, however, the heating effect of a current does not depend on the direction in which it is flowing, this effect can be used for the purpose.

We therefore base our measurements on the heating effect and measure alternating currents and pressures in what are called **virtual amperes** and **virtual volts** respectively, which are defined as follows:—

A virtual ampere is one which will produce the same heat in a resistance as a steady current of one ampere will produce in the same time, and it can be shown that *the virtual value of the current is* $\cdot 707 \times$ *the maximum current.*

Similarly, *a virtual volt is one which, when applied to the ends of a resistance, results in the same heating effect as in the case of a steady pressure of one volt applied for the same time,* and *the virtual value of the pressure is* $\cdot 707 \times$ *the maximum pressure.*

Virtual values are often spoken of as " the square root of the mean square " or " root mean square " or " R.M.S." values, but we need not go into the " why " and the details of this.

7. Reactance, Impedance, Resonance.

In the case of continuous currents, Ohm's law leads to the fact that the current I (amperes) which a pressure E (volts) drives through a resistance R (ohms) is given by:—

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}, \text{ or } I = \frac{E}{R} \text{ or Amperes} = \frac{\text{Volts}}{\text{Ohms}}.$$

The law for alternating currents, corresponding to Ohm's law for continuous currents, is expressed thus:—

$$\text{Current} = \frac{\text{Pressure}}{\text{Impedance}},$$

where **impedance** is to an alternating current similar to what resistance is to a continuous current. In fact for the purpose of the beginner we may regard impedance as the effective resistance encountered by an alternating current. (It is customary to say that an impedance is equal to so many *ohms*.)

Now it has been indicated that there are three main properties of an electric circuit, viz. resistance, inductance, and capacity, and that whilst with continuous currents all that need be troubled about is the resistance, with alternating currents all three factors exert an influence (and so also does the frequency) and all these factors must be taken into account. You will therefore be prepared for the statement that the impedance encountered by an alternating current involves the resistance, inductance, and capacity of the circuit, and the frequency of the alternating pressure and current.

For simplicity we will consider first a circuit containing resistance and inductance but no capacity, and we will

assume an alternating pressure E at frequency f to be applied: it can be shown that

$$\text{Impedance} = \sqrt{(\text{Resistance})^2 + (\text{Reactance})^2}$$

and that

$$\text{Reactance} = 6fL \text{ (approximately)},$$

where L is the inductance of the circuit. If, further, we assume the resistance to be so small that it can be neglected, the whole impedance becomes equal to the reactance, and we have for the current—

$$\text{Current} = \frac{\text{Pressure}}{\text{Impedance}}, \ i.e.\ I = \frac{E}{6fL}.$$

It has been stated that in an inductive circuit the current lags behind the pressure, and hence the reactance above is sometimes referred to as *positive reactance*: since its value is $6fL$, positive reactance evidently increases with the frequency.

Now consider a circuit with resistance and capacity but no inductance. In this case it can be shown that

$$\text{Reactance} = \frac{1}{6fC} \text{ (approximately)},$$

where C is the capacity of the circuit. If, again, we assume the resistance to be small and negligible, the whole impedance becomes equal to the reactance, and we have for the current

$$\text{Current} = \frac{\text{Pressure}}{\text{Impedance}}, \ i.e.\ I = \frac{E}{\frac{1}{6fC}} = 6fCE.$$

It has been stated that in a capacity circuit, the current leads in front of the pressure, and hence the reactance above is sometimes referred to as *negative reactance*: since its value is $\frac{1}{6fC}$ it evidently decreases as the frequency increases.

Consider now a circuit with both inductance and capacity, and again for simplicity imagine the resistance so small as to be negligible. We have seen that the inductance causes lag of current and the capacity causes lead of current; the lag really depends on the value of the positive reactance $6fL$ and the resistance, and the lead depends on the value of the negative reactance $\frac{1}{6fC}$ and the resistance. Clearly (still neglecting the resistance) if these two reactance values are equal there will be neither lag nor lead: in other words, there will be neither lag nor lead if the frequency f be so chosen that

$$6fL = \frac{1}{6fC} \text{ or } f^2 = \frac{1}{36LC}$$

$$\text{or } f = \frac{1}{6\sqrt{LC}}.$$

We arrive then at this fact: If L be the inductance of a circuit (in henries) and C its capacity (in farads), and if an alternating current be sent through the circuit, there will be lag or lead of current according as to whether the positive reactance or the negative reactance is bigger, but if the frequency be so chosen that it is numerically equal to $\frac{1}{6\sqrt{LC}}$ there will be neither lag nor lead, and the impedance of the circuit, being made up only of the resistance (since the two reactances have cancelled), *is less than it is at any other frequency*, and the current will be very big (we are taking the resistance to be very small). Such a circuit is said to be **in resonance**: *resonant circuits are of importance in wireless.*

Some peculiar results happen if an alternating current circuit is in resonance. Consider for example a circuit A of resistance 5 ohms and inductance 5 henries in series with a circuit B of resistance 10 ohms and capacity ·5 microfarad. If we work out the value of $\frac{1}{6\sqrt{LC}}$ for this circuit

from its known value of L and C we get roughly the figure 100. Now suppose an alternating pressure of 200 volts *at a frequency of* 100 be applied to this circuit. Note that we have taken a frequency f for the alternating current equal numerically to the value of $1/6\sqrt{LC}$ for the circuit, *i.e.* we have chosen a condition for resonance. Now if we were to calculate the values of the pressures at the ends of A and B, it would be found that although the applied pressure is only 200 volts, *really big pressures of nearly* 15,000 *volts would exist at the ends of* A *and* B *respectively.*

As the student will see in the next chapter, in a wireless transmitting station we have a primary circuit in which a rapid alternating current of frequency f, say, is circulating. The secondary of this circuit consists of the transmitting aerial, involving inductance L and capacity C made up with inductance coils and condensers. Now suppose the aerial inductance and capacity be varied until $1/6\sqrt{LC}$ has the same value as f. The circuits will then be *tuned to resonance,* as it is termed, the currents in the aerial will be in step or in phase with the E.M.F., and as the resistance of the aerial is small, such currents will be large. Further, as in the numerical example quoted above, there will be big pressures across the inductance and capacity circuit, *i.e.* between the top of the aerial and the earth. These large currents and pressures result in strong electric and magnetic fields, and, as will be seen later, both these effects lead to strong radiation from the aerial in the form of wireless waves.

In the above example of resonance the capacity and inductance were in series and such a case is often referred to as *series resonance.* Another peculiar result occurs if a capacity and inductance be in parallel in an alternating current circuit and the condition for resonance be practically satisfied. If an example of this type be worked out, it will be found that although *the currents in the two branch circuits may be quite definite and even large, the current in the main circuit and through the alternator may be quite small:* such a case is often referred to as *parallel resonance.* As you will see later, the principles of series and parallel

resonance are made use of in wave traps (acceptor and rejector circuits) employed in wireless receiving circuits.

So far we have defined a high frequency oscillatory current simply as an alternating current whose frequency is about 100,000 cycles per second or more: in wireless, where resonance plays such an important role, it is customary to say that an oscillatory current is an alternating current flowing in a circuit whose resistance is very small, the frequency being $1/6\sqrt{LC}$ where L is the inductance of the circuit in henries and C is the capacity in farads.

The preceding is only a very elementary treatment which omits many factors, so that the formulae and the results only approximate to what occurs in practice. It is, however, intended merely to give you a general idea of what is always at first a somewhat difficult problem. But just one point may be stated in case our Physics friends may grumble: the 6 in the preceding formulae should really be 2π (pi) or $2 \times 3{\cdot}14159 \ldots$ which is, however, near enough to 6 for our purpose.

It may be noted in passing that the resistance of a solid conductor to high frequency currents is very much greater than its resistance to steady or continuous currents. This is partly due to the fact that the oscillations have not time to soak or sink into the metal, so that only the skin or surface contributes to the conduction. Stranded insulated wires, comparatively thin, are largely used for high frequency currents owing to the larger proportion of surface area available.

CHAPTER VI.

WIRELESS TELEGRAPHY AND WIRELESS TELEPHONY. BROADCASTING.

1. Waves.

You know that if the prongs of a tuning fork be put in vibration a **sound wave** is set up in the air which can be detected by the ear. The air in the vicinity of the vibrating body executes a slight to and fro movement in step with it; this movement is communicated to the air in front, and so on, until finally the drum of the ear is reached: this responds and the sound is heard.

An **oscillation** is a single swing of the vibrating fork from one extreme position to the other. A **vibration** is a double swing—a " to and fro " movement. The **wave length** is the distance the wave travels during one complete vibration. The **frequency** is the number of complete vibrations in one second. Hence you will see that the **velocity** of the sound wave, *i.e.* the distance it travels in one second, is evidently given by the expression:—

Velocity = (Wave Length) multiplied by (Frequency).

Now the velocity of sound waves in air is practically constant and equal to about 1120 feet per second; hence it follows that *the faster the fork vibrates*, i.e. *the higher the frequency, the shorter will be the wave length*, and conversely, *the lower the frequency the longer will be the wave length*, for in each case the two multiplied together is 1120. The **periodic time** is the time taken for one complete vibration.

Remember that these sound waves are *waves in the air*: if the air between the fork and your ear were removed you would not hear a sound although the fork might still be vibrating. Sound waves have nothing whatever to do with the aether, but wireless waves *are* waves in the aether, not waves in the air.

Note this, too, in passing (we have already mentioned it). If you look at your newspaper you will find, for example, that the wave length of the wireless wave of the London Regional is 356·3 metres and the frequency is 842 kilocycles or 842,000 cycles per second (or "vibrations" if you like), so that the wave length multiplied by the frequency gives about 300,000,000 and this is the velocity of the wireless wave in metres per second. You will get the same number if you take any other station. Clearly *the bigger the wave length the less the frequency*, for the two multiplied together always give the same number. Further, this wireless wave velocity is the same as that of light (186,000 miles *or* 300,000 kilometres *or* 300,000,000 metres per second).

Suppose now you are sitting on a swing which is going to and fro. Just as you are going forward suppose someone gives you a forward push and that this happens every time you go forward: you will build up a big swing. But the pushes must be given at the right time: in scientific language the *frequency* of the pushes must be equal to the *frequency* of the swings and the two must be in step or in phase—a forward push when you are going forward.

Now let us go back to our sound waves. If you uncover the strings of a piano and sound a tuning fork near them, you will notice that several of the strings are affected by the waves from the fork, but you will find that that particular string which has the same vibration frequency as the fork will be affected most, and it may be set so strongly in vibration that it gives out the same note as the fork.

This is similar to the swing and pushes. The first wave hits the piano string forward, say: the string comes back, and then just when it starts forward the second time, the second pulse from the fork just reaches it and hits it forward again, and so on; thus the vibrations of this string are increased. Another string that has not got the same frequency as the fork is hit forward by a later wave when it is moving back and so, just as would happen with the swing, it soon pulls up.

Similarly, when a piano is being played it sometimes happens that a vase in the vicinity is set strongly in vibration when a certain note is struck, due to the fact that its dimensions, etc., are such that it has a *natural frequency* of its own equal to that of the note which affects it.

The above are examples of what is called **resonance.** The two vibrating bodies which have the same frequency are said to be *in resonance* or **in tune** with each other. This idea is important in wireless. The *general principle* is just the same as that of the resonance in an alternating current circuit dealt with in Chapter V.: we had resonance there when *f*, the *frequency* of the alternating current in the circuit was equal to $1/6\sqrt{LC}$ where L was the inductance and C the capacity of the circuit, and this $1/6\sqrt{LC}$ is really an expression for the natural (electrical) *frequency* of the circuit.

Water is another well known medium in which a wave motion can be set up. Long waves in water are caused by wind and the gravitational pull of the earth. Imagine, however, that a stick is moved gently up and down at the centre of a large pond. In this case genuine water waves will be set up, *i.e.* the particles of water will move up and down forming in succession " crests " and " troughs," and a wave motion will spread outwards in all directions.

Consider the water heaped up in a crest. Now there is an attraction, known as *surface tension*, between the molecules on the surface of water, and this force of surface tension tends to flatten out the water again, and it moves downwards to the normal position. In moving downwards, however, another force is called into play known as the *force of inertia* and this carries the water below its normal position so that the crest changes into a trough. The force of inertia now ceases, but the surface is once more stretched and the force of surface tension comes on again, thus raising up the trough, and the action is repeated. (The two forces are at right angles to each other.) These movements are communicated to the water beyond, and the wave motion spreads outwards.

The above is rather like what is taking place in wireless, as you will see presently.

2. More about the Oscillatory Discharge of a Condenser.

Before going further you must read again Art. 4 of Chapter IV.

Now take the condenser to be giving an oscillatory discharge. Such a surging of electricity to and fro, which surges get gradually weaker and finally die out may be pictured to the eye in the way shown in Fig. 83. As a result of all this the aether in the vicinity is undergoing a regular, periodic, change of state—regular periodic variations of electric and magnetic strains at right angles to each other—and this periodic variation of state is transmitted with a definite velocity throughout the aether: that is, we have an **electric wave** or **electromagnetic wave** sent out through the aether with a velocity which is equal to the velocity of light. With suitable apparatus these are the waves used in wireless telegraphy, telephony, and broadcasting.

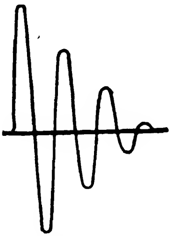


Fig. 83.

In wireless we have high frequency oscillations in the transmitting aerial just as we have in the discharging condenser: this gives rise to electric and magnetic strains in the aether at right angles to each other as explained in Art. 9 of Chapter I., and these are constantly changing—varying periodically. The result is that we have a wave motion set up in the aether—the wireless waves. Maxwell proved mathematically, long before wireless came to the front, that if at any place we have electric and magnetic forces at right angles and the two are rapidly changing we are bound to have an "electromagnetic disturbance" spreading out from the place in the form of a wave motion.

Think for a moment what it is we really have in the condenser discharge. We have a condenser which possesses *capacity*. We have a wire joining the plates which possesses *resistance* and also *inductance*. In wireless the resistance

of a circuit is always kept as small as possible. Let us neglect the resistance then and say that the two main things we have got are **inductance** and **capacity**. Of course inductance is only very small in a straight wire, but it is much bigger in a coil of wire.

Now it can be proved that the frequency of the vibrations of the electrons in this discharging condenser depends on the inductance and the capacity. *The bigger the inductance and the bigger the capacity the slower are the oscillations,* i.e. *the less the frequency.* And, of course, since the less the frequency the bigger the wave length, another way of putting this is that *the bigger the inductance and the bigger the capacity the bigger is the wave length* of the aether waves that are sent out.

If you seriously think about the matter, you will see that the above is bound to be the case. Inductance is noted for its "opposition": if the electrons start to go one way, inductance tries to stop them; if they go the other way inductance again tries to stop them; if they are moving and want to stop, inductance tries to make them keep on. The result is that if electrons are started swinging to and fro in a circuit, inductance slows them up, and therefore the frequency is reduced and, of course, the wave length increased.

Similarly a condenser tends to "store" electrons, giving them out again only when compelled to do so. This is putting the fact rather unscientifically, but it indicates that the effect is to slow down the swings, *i.e.* reduce the frequency and increase the wave length.

In fact if we neglect the resistance in the circuit it can be shown that—

$$\text{Frequency is proportional to } \frac{1}{\sqrt{LC}};$$

$$\text{Wave length is proportional to } \sqrt{LC},$$

where L is inductance and C capacity. Increasing either L or C, therefore, increases the wave length and reduces the frequency of the waves sent out.

In the oscillating circuit we have been dealing with we started off with a condenser fully charged and we joined the plates by a wire or coil thus getting oscillations of electrons and a train of waves: but in a short time the condenser is discharged and the waves stop. If we want another train of waves we can do it by disconnecting the wire, charging up the condenser again, then putting on the wire, and so on. This is not a practical method, and it gives very poor waves.

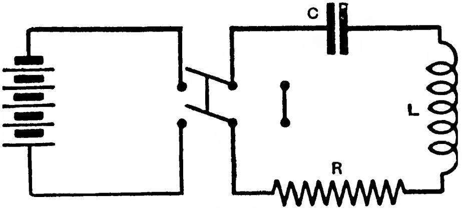


Fig. 84.

Now look for a moment at Fig. 84. By turning the switch to the left current flows from the battery, charges up the condenser, and then stops. By moving the switch to the right the condenser plates are joined so that an oscillatory discharge takes place through the coils, waves go out, and then everything is steady. By moving the switch backwards and forwards, however, so that the condenser is constantly being charged and discharged, a series of waves can be sent out. But this again is not an ideal method and it also gives poor waves. More practical methods are given in the next section.

Oscillations such as those we have been considering in these condenser discharges—oscillations which gradually weaken or decrease in amplitude and finally die out—are spoken of as *damped oscillations* and the resulting waves are called **damped waves.** They are still used for wireless *telegraphy* (Morse Code—"dot" and "dash") but for wireless *telephony* (speech, etc.) undamped oscillations and undamped or **continuous waves,** which do not weaken and die down, are mainly used, as will be seen presently.

3. Wireless Telegraphy with Damped Waves.

You are naturally more interested in the reception than in the production of wireless waves, but we will indicate very briefly the *principles underlying the methods* of production and transmission: naturally in this book we cannot go into the complicated details of modern transmitting stations.

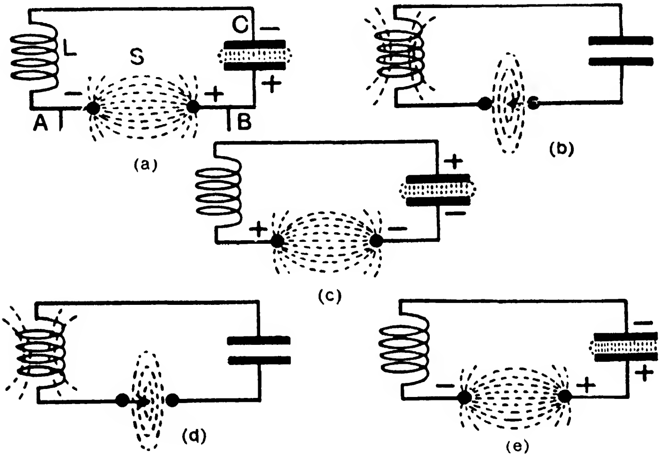


Fig. 85.

Now look at Fig. 85. Here C is the condenser (capacity) and L is the coil (inductance), and the two wires A and B go to a battery or other source of electricity for charging the circuit. Note, however, that there is a gap S (it is referred to as the **spark gap**).

When you switch on the battery the condenser is charged until the potential difference across the gap is big enough to overcome the resistance of the air in the gap: then a spark passes. This spark is, of course, oscillatory, and waves pass out. When the oscillations have died down, however, and the waves ceased, the battery again charges up the condenser and the action is repeated. Thus if you have a key in the battery circuit joined to A and B you

will get a series of waves going out as long as the key is kept closed. Such a succession of waves might be represented to the eye as shown in Fig. 86: in this figure we are assuming the frequency of the oscillatory discharge at each spark to be 1,000,000 cycles per second (the "wireless frequency," as we may call it) and that the "sparks" occur at the rate of 1000 per second (the "spark frequency").

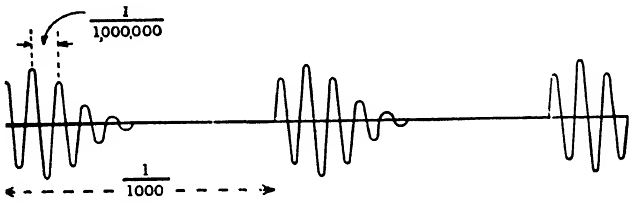


Fig. 86.

Notice that the condenser (Fig. 85) is charged first one way then the other due to the electrons surging backwards and forwards, and that we have electric lines of force at (*a*), (*c*), and (*e*), and magnetic lines of force at (*b*) and (*d*), the latter being at right angles to the former: and our wave travels out through the aether in a direction at right angles to both the electric and magnetic forces. The figure shows the state of affairs during *one* complete to and fro surge.

But there is a little point we must mention here for the sake of accuracy. In Fig. 85 (*a*) we have an electric field and electric lines but no current and no magnetic lines; in Fig. 85 (*b*) we have a current and magnetic lines but no electric lines, and so on. Thus at the oscillator the electric disturbance and the magnetic disturbance are not in step with each other: one is a quarter of a period behind the other, just like the piston and slide valve of an engine.

Now the progression of the wave through space demands that both forms of energy—electric and magnetic—should exist together and be in step, *i.e.* when one is a maximum the other must be a maximum (or nearly so), and when one is a minimum the other must be a minimum, and it can be shown that this state of affairs does exist at *a distance of*

one quarter of a wave length from the oscillator. Within this distance the energy simply pulsates in and out, but at this distance the magnetic and electric disturbances have got in step and wireless waves pass onwards through the aether with the velocity of light. You will understand this better later.

The above "closed oscillatory circuit," as it is called, does not send out a lot of energy in the form of aether waves. If, however, the condenser plates be opened out, as it were, thus forming an "open oscillatory circuit," we readily get energy passed out in the form of waves, and this is done in practice.

Fig. 87 shows the idea of "opening out" the condenser plates A and B, and it also shows the electric lines (dotted) and the magnetic lines at right angles. We have not put a spark gap or shown the charging arrangement in Fig. 87 because at present we merely want you to get the general idea.

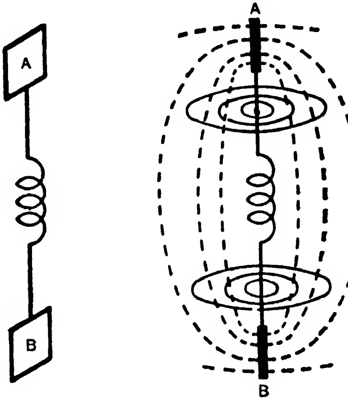


Fig. 87.

In 1888 Hertz published an account of certain experiments of his on electric waves, and these are often regarded as the starting point of practical wireless.

In doing these experiments Hertz used a piece of apparatus called an **induction coil.** This consists of a primary coil wrapped round a bar of iron and joined to a battery and key. This primary has a vibrating piece in its circuit which, as long as the above key is closed, keeps starting and stopping the current—just as the vibrating piece in an electric bell keeps making and breaking the current as long as the bell push is closed. On the outside of this primary coil is a secondary coil and this coil contains a spark gap.

When the key in the primary is held down the vibrating piece keeps starting and stopping the primary current, induced currents are therefore constantly being set up in the secondary coil and sparks pass quickly at the gap.

Hertz's **oscillator** or **transmitter** consisted of two metal plates connected to the spark gap (Fig. 88), the capacity between the two plates and the inductance of the connections between them forming the necessary capacity and inductance for the oscillatory circuit. You will see that Hertz really opened out the condenser plates of Fig. 85.

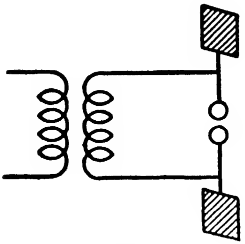


Fig. 88.

The action is identical with that already explained. When the induction coil is worked, the upper plate, say, is charged to a higher potential than the lower plate, then a spark passes, and the potential is equalised by very rapid oscillations of electricity (electrons) in this circuit, and waves pass out.

To detect the waves at a distance Hertz used a circle of thick wire (Fig. 89) fitted with a gap. When the waves from the oscillator passed this **detector** they set up oscillations in it and sparks were obtained at the gap. Further, he found that the sparks were strongest if he used a detector having such dimensions, that its frequency as an oscillator was equal to the frequency of his oscillator which started the waves. This is again, of course, an example of our old friend tuning or resonance.

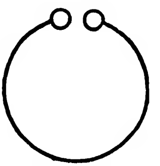


Fig. 89.

About 1895 Marconi discovered that if one of the spark gap terminals in Hertz's transmitter were connected to a plate buried in the ground, the surface of the earth could be used as one plate of the condenser; and also that the higher the other plate was above the ground the greater was the distance over which he could transmit the waves.

He found that an actual upper plate was unnecessary, and that a vertical wire (the aerial) supported by a kite or masts gave similar results, the capacity in this case being spread out along the wire: in other words the aerial and earth formed a condenser, the wire being one coat, the earth the other, and the air in between the dielectric.

Fig. 90 shows the principle of Marconi's transmitting arrangement, the variable inductance in the aerial circuit enabling the circuit to be tuned to send out various wave lengths. The induction coil is shown on the left.

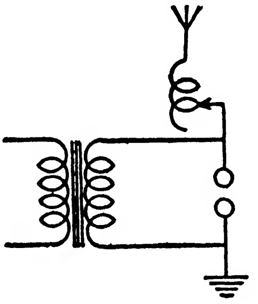


Fig. 90.

At the receiving station the waves from the transmitting station fell upon a similar aerial and set up electrical oscillations in it, the receiving aerial being tuned to suit the arriving waves by variable inductances and capacities.

You will understand how tuning works. If a condenser and an inductance coil be joined to the receiving aerial they really become part of that aerial. If the coil be made bigger or the condenser bigger the frequency of any oscillations set up in the aerial will be reduced, and if they are made less the frequency will be increased. By altering the condenser and inductance, therefore, we can so arrange matters that when a wave comes up and starts an oscillation in the aerial that surge will rush along the aerial and come back just in time to be caught by the next wave reaching the aerial—just in fact like the swing and the pushes delivered at the right moment. In other words we make the frequency of our receiving aerial system equal to the frequency of the arriving waves and so get resonance.

Always bear in mind that increasing the inductance or increasing the capacity will tune the aerial to receive a longer wave and decreasing them will tune it to suit a shorter wave. Remember, too, that the arriving *waves* cause *electrical oscillations* (H.F.) in the aerial.

Fig. 91 shows three methods we frequently use in tuning the receiving aerial to the arriving waves. In (*a*) tuning is done by a variable inductance, in (*b*) by a variable condenser in parallel with the inductance (which may be fixed or variable), whilst in (*c*) a variable condenser is also in series with the inductance (which may again be either fixed or variable). You will learn more about these arrangements later.

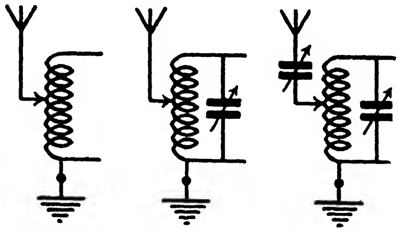


Fig. 91.

Now having got the aerial tuned to the waves that are coming, we must have some device fastened to the aerial to indicate to us that the waves have arrived and for this purpose what was called a **coherer** was used in the early days.

A simple type of coherer is shown in Fig. 92. Two brass, copper, or silver discs *dd* are soldered to the ends of two copper wires *w*, are fitted into the glass tube *gg*, and a thin layer of filings rests lightly between the discs. If the ends of the copper wires be joined to a battery and an electric bell, the contacts made by the filings between the discs may be so adjusted that the current passing will not be strong enough to ring the bell. If, however, waves from a distant oscillator fall upon the circuit containing the coherer after this adjustment is made, the contacts at once become good and the bell in the circuit rings. If the coherer is slightly tapped the contacts fail and the arrangement is again ready to detect the arrival of the waves.

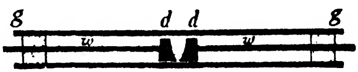


Fig. 92.

In Marconi's coherer the plugs *d*, *d* were of silver, the filings a mixture of nickel and silver, and the tube was exhausted and sealed.

You will now be able to follow one of Marconi's earlier transmitting circuits for wireless *telegraphy*. The spark gap of the induction coil consisted of two small brass spheres sparking across the diameters of two larger ones (Fig. 93).

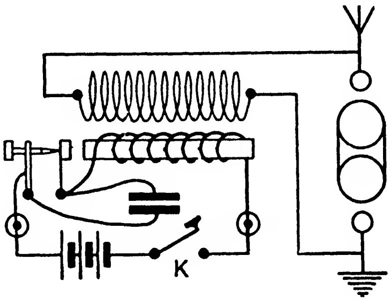


Fig. 93.

The key K (which we call the *sending key*) in the primary circuit is kept closed for a long or for a short time, thus producing trains of sparks for long or for short times and producing at the receiving end corresponding signals lasting for long or for short times. These form the "longs" and "shorts," *i.e.* the "dashes" and "dots" of the Morse

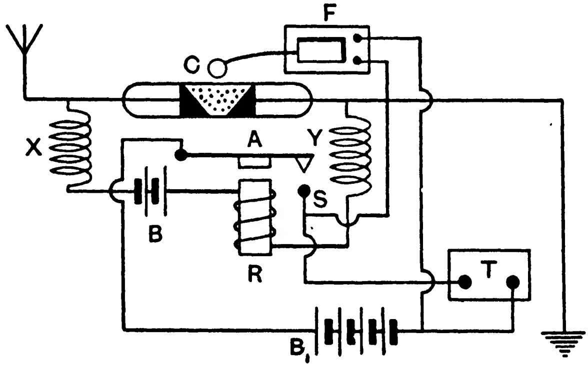


Fig. 94.

Code used in telegraphy, and intelligible messages can thus be sent. We will explain this a little more fully presently.

One of Marconi's early receiving circuits is shown in Fig. 94. The waves arriving at the aerial result in the filings of the detector C sticking or "cohering," and current

from B flows in the direction BRYCXB. This current magnetises the electromagnet R, so that the iron piece A is attracted, making contact with the stud S. The circuit of the battery B_1 is now closed, with the result that current flows from it through the telegraph instrument T and the signal is recorded. At the same time a current passes from B_1 through the coils of the electric bell F, the hammer of which taps C and decoheres the filings, so that C is again ready to respond to the waves.

You should notice particularly that the oscillations in the aerial cause the coherer to work, and this really causes a steady current from a separate battery to work T.

It is important that you should picture how the operator at the transmitter controls the wireless waves (by key K in Fig. 93) so as to send messages to the operator at the receiver which he can understand.

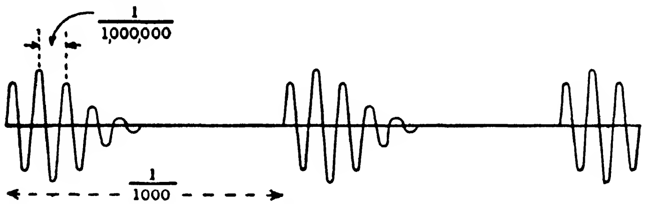


Fig. 95.

By means of the key the currents can be made to flow up and down the aerial for long or for short periods of time. For a long signal the key is kept down three times as long as for a short signal. Combinations of longs and shorts—dashes and dots—form letters according to the code known as the Morse Code, *e.g.* A · —, B — · · ·, C — · — ·, etc.

Now in the spark system which we have been considering, oscillating currents are being produced while the spark is passing: they gradually die down and then, when another spark passes, they flow again and gradually die down, and so on. Hence there are times when wireless waves are being sent out by the aerial and times when no wireless

waves are being sent out, although the key K may be depressed all the time. Fig. 95 will make this clear.

The time between the successive crests of the high frequency or oscillatory currents is very short, of the order $\frac{1}{1000000}$ of a second (Fig. 95). On the other hand the time between the sparks is longer, of the order $\frac{1}{1000}$ second. The time the operator keeps the key down in order to send a short signal or dot is much longer still, viz. $\frac{1}{5}$ second. It is thus clear that even during the sending of a dot there is a succession of many sparks—say about 200—producing the signal, so that the fact that the trains of oscillations have gaps between them causes no inconvenience in the sending of the dot and dash signals.

We have seen that in addition to the tuned receiving aerial we must have some arrangement for giving us intelligible signals, *e.g.* some telegraph instrument such as a sounder or, say, a telephone. We have also seen how a coherer, when the rapid oscillations in the aerial are passed on to it, causes a current from a separate battery to work the telegraph instrument. The coherer, however, was soon replaced by other devices of which the **crystal** and the **valve** are the two mainly used now. We will consider the crystal for a moment, and then deal more fully with both the crystal and the valve in Chapter VIII.

Now the oscillating currents set up in the receiving aerial are of too high a frequency (a million and more per second) to work, say, a telephone or a telegraph sounder directly, for the moving parts of these instruments would not have time to move between one rush and the next one in the opposite direction. If, however, we wipe out, in some way, the currents in one direction then the currents in the other direction will work the instrument. In other words, what we want to do is to produce in the recording part of the receiving circuit—say the telephones—" one direction " currents which must of course vary according to the trains of waves arriving at the aerial. This is what the crystal does.

The action of a crystal then depends on the fact that current can only pass through it in a certain direction, so

that it changes an oscillatory current into a one direction current by stopping the flow in one direction. Fig. 96 shows a method of using a crystal as a detector or **rectifier,** telephones being used as a receiver. The oscillations in the aerial due to the arriving waves tend to set up oscillatory currents in the crystal circuit, but the crystal refuses the current in one direction, so that a one direction current flows each time a group of oscillations is set up in the aerial, *i.e.* each time a spark passes at the transmitter. The note heard in the telephones is therefore *of the same frequency as that of the sparks* at the transmitter, and it starts and stops when the train of sparks starts and stops.

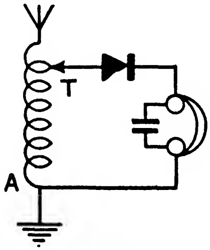


Fig. 96.

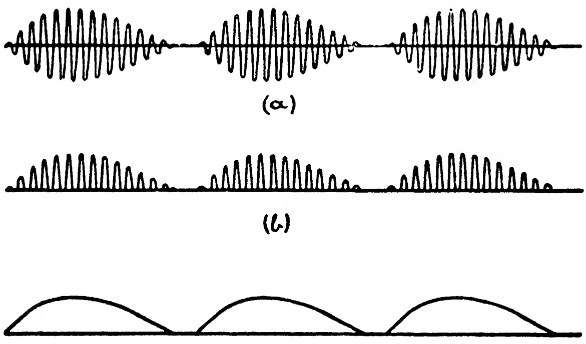


Fig. 97.

You will better understand this **rectifying action** of the crystal and the resulting effect on the telephones if you look at Fig. 97 which shows the application of the crystal to the incoming oscillations. The crystal may be regarded as wiping out all the alternations or half puffs say below the centre line and allowing only the half puffs above the

line to pass. These half puffs or rectified currents which, although varying in strength, flow only in one direction, pass through the telephones.

Since the telephones are quite unable to respond to the separate high frequency oscillations (which only occupy, say, $\frac{1}{1000000}$ second) of Fig. 97*a*, they will still be unable to respond to the separate puffs of the rectified current of Fig. 97*b*, but these separate puffs may be looked upon as collected together to form a slowly varying one direction current, as indicated in Fig. 97*c*, and to this the telephones respond.

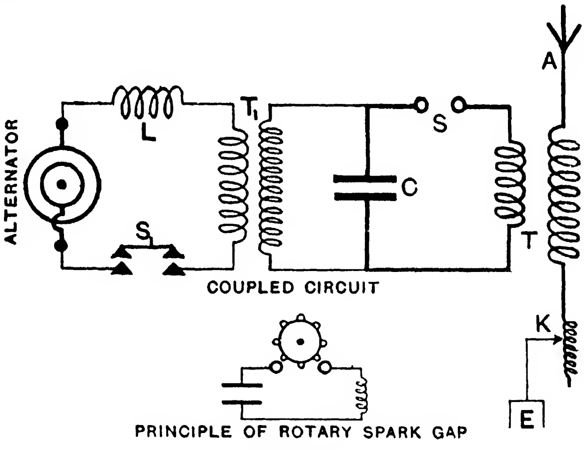


Fig. 98.

Using the numerical value in Fig. 95, we have a rush of current through the telephones every $\frac{1}{1000}$ second, which tends to attract the iron disc as it rises and to allow the iron disc to go back as it falls. The telephones can easily respond to this frequency, so that they send out sound waves at a frequency which is well within the range of the human ear.

You will notice that the crystal is often spoken of as a detector, and you buy " crystal detectors " at your wireless dealer's: it would be far better if we always spoke of them

as rectifiers—things which rectify alternating current, *i.e.* change it into unidirectional current or current in one direction.

Valves are also used as detectors or rectifiers in a somewhat similar way to the crystal, as will be seen later.

It is impossible to explain in this book the various improvements which have been made in these **spark methods** of transmitting wireless telegraphy (damped waves): nor is it necessary since spark transmitters are largely being replaced by other transmitters giving continuous waves.

One improvement was to " couple " the closed oscillatory spark gap circuit of Fig. 85 to the transmitting aerial circuit as indicated in Fig. 98 so that the former *induces* the oscillations in the transmitting aerial. The contact K and therefore the inductance in the aerial is altered until the frequency of the aerial circuit is equal to that of the spark circuit. The " charging " is from the secondary of a transformer T, the primary of which is joined to an alternator. S is the key to produce the " longs " and " shorts " of the Morse Code.

The " coupling " must not be too tight otherwise the aerial transfers energy back to the condenser circuit and this cuts down the energy radiated from the aerial. Sometimes a rotary spark gap is used: a wheel with projecting studs rotates between fixed studs in the condenser circuit and is so arranged that fixed and moving studs come opposite each other at the instant the condenser is fully charged, *i.e.* just when the spark is required.

In what is called the **quenched spark gap system,** the electric discharge across the spark gap oscillates only a few times before it is quenched or extinguished and *the gap made non-conducting*; this is done just at the instant that the maximum energy is transferred to the aerial circuit for the first time. The aerial circuit in this case cannot transfer energy back to the closed circuit to the extent it does in the preceding case, for the gap is non-conducting and current cannot flow. Thus the damping in the aerial circuit is very slight, so that its oscillations continue, and

there is a large number in each train of waves; hence tight coupling can be utilised in such a case. Fig. 99 shows the oscillations in the primary or closed circuit and in the

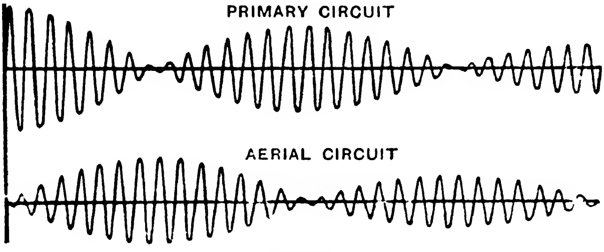


Fig. 99.

secondary or aerial circuit when the coupling is tight, and Fig. 100 shows the oscillations when the spark is quenched after 2½ oscillations. The figures clearly indicate the general principles referred to above.

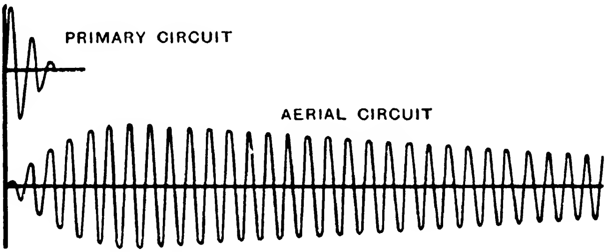


Fig. 100.

4. Wireless Telegraphy with Continuous Waves.

The damped oscillations and waves of the spark transmitter are all right for telegraphy but for telephony, broadcasting, and television undamped oscillations and undamped or **continuous waves** (C.W.) are used, and they are also displacing damped waves for telegraphy. Fig. 101 depicts to the eye an undamped oscillation or an undamped wave.

This simply means that ***undamped*** high frequency oscillatory current—produced in various ways—is made to circulate in the transmitting aerial, and this gives rise to undamped waves in the aether which travel out in the way we have already indicated. When these waves meet the receiving aerial, undamped electrical oscillations are induced in it of the same frequency as those at the transmitting station, the receiving aerial being of course tuned to the arriving waves. The detector then picks these up, wipes out, say, the left hand puffs of current, and allows the right hand puffs, *i.e.* a unidirectional current, to pass through the recording instrument. There is an important point here as to how the telephones respond to these, but we will come to that presently.

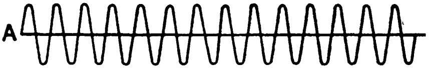


Fig. 101.

A method of producing the undamped high frequency oscillations at the transmitting end, due largely to Poulsen, makes use of a **carbon arc** lamp, and the principle will be gathered from Fig. 102 where the arc practically replaces the spark gap in preceding circuits. Imagine the arc formed and the condenser fully charged so that an oscillatory current starts up in the closed circuit. During one half cycle the oscillatory current will be flowing through the arc in the same direction as the current through the arc from the battery, while during the next half-cycle the oscillatory current will be in the opposite direction to the main arc current.

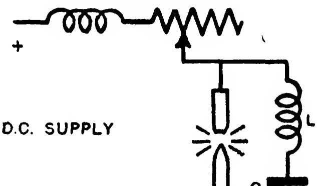


Fig. 102.

Now the resistance and potential difference across an arc decrease when the current increases, and increase when the current decreases. Hence when the oscillatory current

goes through in the same direction as the main arc current, the resistance is lessened, the damping is reduced, and therefore the oscillations tend to continue. When the oscillatory current goes the other way, the potential difference on the arc increases and charges up the condenser until the potential difference across the arc is normal again, at which stage the condenser discharges, and the oscillatory current is maintained at constant amplitude.

It is evident, therefore, that the oscillatory currents produced by an arc are undamped or continuous oscillations, and any waves thrown out will be undamped or continuous waves.

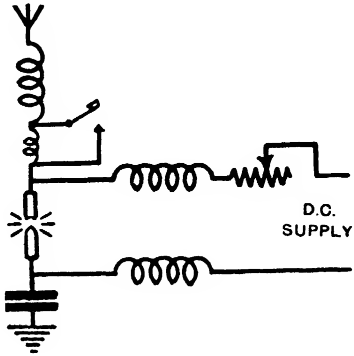


Fig. 103.

Fig. 103 shows one arrangement of the arc at a transmitting station for the production of these undamped or continuous waves. The arc is in series with the aerial, and a condenser is joined between it and the earth to stop the direct or continuous current from going to earth. In the preceding spark systems the transmitting key started and stopped the sparks in order to produce the signals. This is inconvenient here for, at a stop, the arc would be extinguished and would have to be re-struck—a bothering business. Hence the key is put across part of the inductance, as shown, thus short-circuiting it and altering the wave length being transmitted. When the key is closed the wave going out is the signal: when it is opened the new wave going out denotes the " space " between signals. Of course, Fig. 103 is only diagrammatic—it is merely intended to show the position of the arc and key.

Another method of producing undamped oscillations and continuous waves is to use a **high frequency alternator** (a

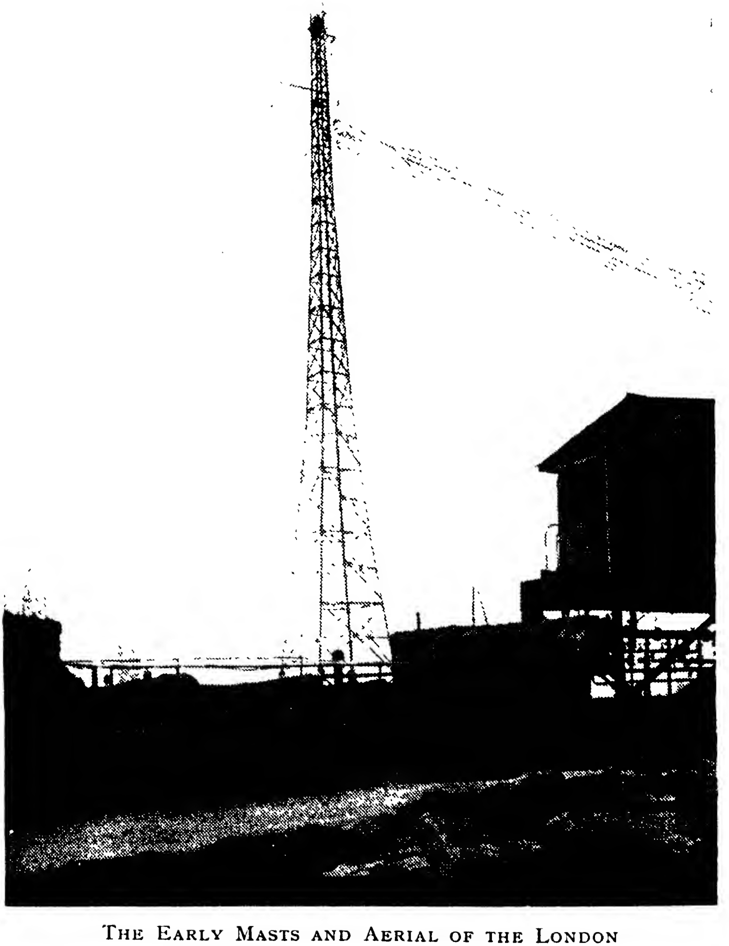
generator which gives alternating current). In order to produce the very high frequencies required in wireless the moving parts of the alternator must rotate very rapidly thus involving great stresses in the machine, so that the ordinary alternator construction will not do. Special high frequency alternators—known as Alexanderson alternators after their inventor—are used for the purpose. Further, the frequency of the alternator is often increased by some type of **frequency raising transformer.** Thus the Telefunken Company have installed high frequency alternators and then have multiplied the frequency of these alternators four times by means of frequency changing transformers. Details of both the alternators and the transformers, however, belong to the domain of Electrical Engineering, and we cannot go into them here.

It may be mentioned, however, that with these large powers the sending key for the " longs " and " shorts " cannot be put direct into the aerial circuit, but is placed in the circuit of the direct current (low power) which excites the field coils of the generator.

In addition to the " arc " and " alternator " methods of producing continuous waves, **valve transmitters** are in use, and in fact are largely superseding all other methods. Valves and valve transmission will be dealt with later.

It is essential to keep the frequency of the radiation sent out *constant.* If the aerial at the transmitting station were connected direct to the generators even the swaying in the wind would so alter the capacity of the aerial-earth system that the frequency would change. To avoid this the transmitting aerial is not joined direct to the generating circuit but the oscillations are fed through a transformer to the aerial: a separate oscillating valve is used to drive the main transmitter. The frequency is thus governed by the details of the closed circuit and changes in the aerial do not affect it. The main oscillating device is spoken of as the **master oscillator** or the **drive oscillator.** Most B.B.C. stations use this arrangement.

At the P.O. Rugby wireless station a constant frequency is obtained by means of a tuning fork made of " invar "



THE EARLY MASTS AND AERIAL OF THE LONDON BROADCASTING STATION.

metal which is kept in constant oscillation by means of a valve: this is known as **tuning-fork drive.** The currents which are only of tuning-fork frequency are passed through a valve which produces harmonics (*i.e.* multiples) of the original frequency and one of the higher harmonics is picked out by a tuned circuit and fed, after magnification, into the aerial. In yet another method of getting an oscillation of very constant frequency a crystal of quartz is used in place of a tuning fork. This is referred to as the **quartz oscillator** and is largely employed for very short wave transmission. Further details are, however, beyond the scope of this book.

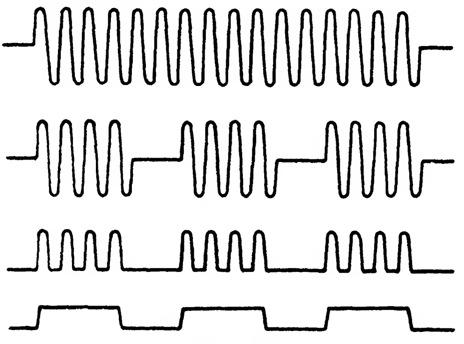


Fig. 104.

Coming now to the receiving end, the continuous or undamped oscillatory currents produced in the receiving aerial can be rectified by, say, a crystal, as already indicated for damped oscillatory currents, and the unidirectional or one direction current passed on to the telephones. But in this case as the current is a "uniform" unidirectional current and not a "rising and falling" unidirectional current, the diaphragm of the telephones will be attracted as soon as the waves arrive and will remain attracted until the waves stop. The receiving operator will thus hear a click when the signal begins and another click when the signal ends (instead of a note all the time the signal, whether

"dot" or "dash," *i.e.* "short" or "long," is passing), and the message will be very difficult if not impossible to read.

Clearly, then, something must be done either at the transmitting end or at the receiving end to break the waves up into short trains of waves, and to do this at such a rate that a note is produced in the telephones. A continuous wave interrupted in this way at the transmitting end is spoken of as an **interrupted continuous wave** or as an I.C.W. The general principle will be gathered from Fig. 104 (compare Fig. 97).

Another method was to insert a rotating arrangement or **chopper** in the detecting circuit whereby this circuit was broken for short intervals of time.

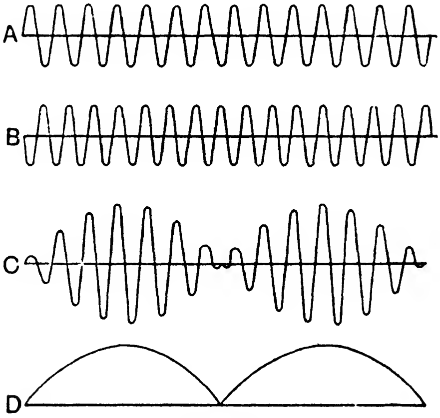


Fig. 105.

The above method has, however, been replaced by the **heterodyne method** due to Fessenden. In this method the incoming oscillations are combined with other oscillations of a slightly different frequency, and the two combined produce a resultant current which increases and decreases in strength at a rate depending on the difference in the frequencies of the two oscillations. Fig. 105 will make the principle clear. Here A depicts the incoming high frequency

oscillations, B the oscillations of a slightly different frequency, locally produced, and C shows the resultant of the two. The telephone responds to D, the actual note heard depending on the frequency of these resultant puffs. The effect rather resembles the phenomenon of beats in music, and it is often called *beat reception*, but this is not correct. The note heard in the telephone is not a beat note but what is called in sound a *combination tone*: this, however, is a detail.

The production of these local oscillations which have to be combined with the continuous oscillations will be understood when valve circuits and reaction have been studied in Chapter X.

5. Wireless Telephony—and Broadcasting—with Continuous Waves.

We can now deal briefly with the sending and receiving of the speech, etc., in wireless telephony (and in broadcasting), using of course these continuous waves.

The undamped high frequency electrical oscillations in the transmitting aerial produce an undamped or continuous wave (like Fig. 101), which is passing out all the time broadcasting is taking place. This wave is called the **carrier wave.**

Joined (in various ways according to the transmitting circuit used) to the transmitting apparatus, and therefore indirectly to the transmitting aerial, is a microphone. When the person broadcasting speaks into the microphone the sound waves cause changes in the microphone current, and therefore corresponding variations in the aerial current, so that we have a resulting current in the transmitting aerial which varies in strength in a most complicated way according to the words spoken. This again in turn produces a complicated aether wave varying according to the words spoken which, when it reaches the receiving aerial, sets up corresponding complicated electrical oscillations in it, *i.e.* oscillations varying in strength in a complicated way according to the words spoken at the transmitting end.

These complicated oscillations in the receiving aerial pass on to the detector which wipes out the puffs at one

side leaving the complicated puffs at the other side to pass through. These latter unidirectional puffs, still complicated according to the words spoken, pass through the telephone or loud speaker, and the words are reproduced.

The essential fact is that the speech of the operator is caused to **modulate** the carrier wave, and the receiving telephone or loud speaker reproduces the sound to which the modulated wave is due.

Fig. 106 (*a*) depicts a carrier wave and Fig. 106 (*b*) a modulated wave when a note is produced in front of the microphone. Of course, the carrier wave should have very many more oscillations shown in it than are given in the figure.

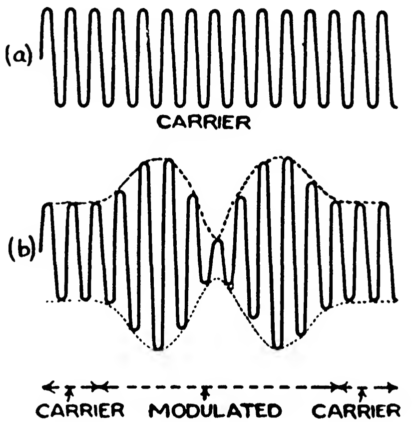


Fig. 106.

Now note these points particularly: (1) The high frequency electrical oscillations in the transmitting aerial—the swinging of electrons to and fro at the rate of, say, a million times per second—are going on all the time. The carrier wave is rushing along through the aether all the time. The high frequency electrical oscillations set up in your receiving aerial (a million per second) are going on all the time.

(2) When the broadcaster speaks he does not alter the frequency of these oscillations or the wave length of the carrier wave, but he does alter the *strength* of the oscillations, *i.e.* the number of electrons taking part in the different swings, and this strength variation depends on the words spoken. It is this strength variation shown by a peculiar irregular shaped curve like Fig. 106 which, when one half

has been wiped out by the detector or rectifier, causes the discs of the telephones or the moving parts of the loud speaker to vibrate in the same way and reproduce the words, and the same applies to the sending and receiving of music.

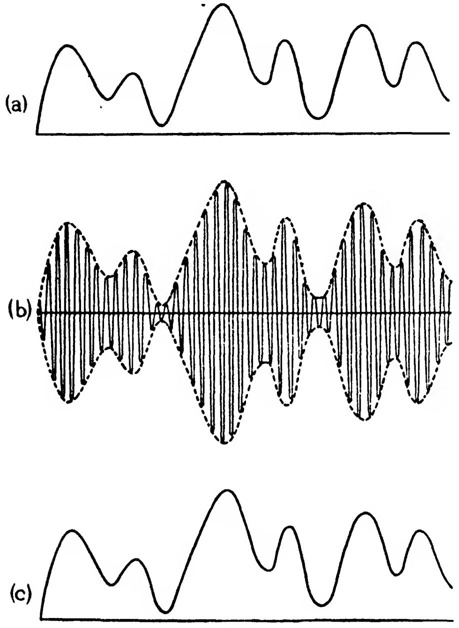


Fig. 107.

(a) Varying current produced in the microphone (by the voice of the broadcaster); this is passed to the high-frequency aerial oscillations which are producing the carrier wave. (b) The "modulation" caused by (*a*): the "modulated wave" on reaching the receiving aerial sets up oscillations corresponding to those at the transmitting aerial and these pass to the receiver for amplification and rectification. (c) The varying current passed finally to the loud speaker: the sound obtained due to (*c*) is an exact copy (or should be) of the sound which caused (*a*).

The carrier wave carries the slower variations produced by the speech and the music through the aether almost as an aeroplane carries its pilot through the air. If the "high frequency" aerial current is not there you can shout as hard as you like into the microphone or sing the sweetest song, and the aether will have none of it: nothing will happen save that the air will carry the sound a short distance.

Incidentally we may mention that the microphone variations produced by the voice are usually strengthened or amplified before being combined with the aerial

oscillations, *i.e.* with the oscillations producing the carrier wave. Similarly at the receiving end the aerial oscillations are frequently magnified or amplified before passing on to the detector valve, and the current variations are again magnified or amplified after the detector valve before being passed on to the telephones or loud speaker. These are details which will be dealt with later.

Fig. 107 gives a kind of diagrammatic sketch of the process we have explained in this section.

6. A Few Facts about Wireless Waves.

Fig. 108 (*a*) shows the electric lines, say, in Hertz's oscillator when it is just about to spark across the gap. When the oscillator begins to discharge the ends of the electric strain lines move along the rods, thus constituting the electric current, and at the same time magnetic strain lines appear as shown at M in Fig. 108 (*b*): the outer portions of the electric lines are approaching the gap. Now the lines do not approach the rods as quickly as their opposite ends move along them, hence they take up the form shown in Fig. 108 (*c*). At a later stage the ends of the lines will have "crossed over" as indicated in Fig. 108 (*d*), and a closed strain loop will be thrown off as shown in Fig. 108 (*e*). The next "surging" will give rise to another set of closed loops (Fig. 108 (*f*)), and so on. It is this detachment of loops which constitutes electric radiation, the loops travelling outwards with a velocity of 186,000 miles per second. It will be noted that the direction of the electric strain is opposite in successive loops, and so also is the magnetic strain, the magnetic strain being, as already mentioned, at right angles to the direction of the electric strain, and both at right angles to the motion. This statement requires a slight modification for scientific accuracy, but you need not trouble about this at present.

Instead of saying that the loops travel outwards, it would be more exact to say that a loop "dies" at one place and is "re-created" at another. Each electric strain line shrinks, in so doing creating magnetic strain

lines, the rise and fall of which re-create loops of electric strain, and so on; hence the effect is equivalent to a progression through space of two sets of strain, electric and magnetic, which constitute the electromagnetic wave.

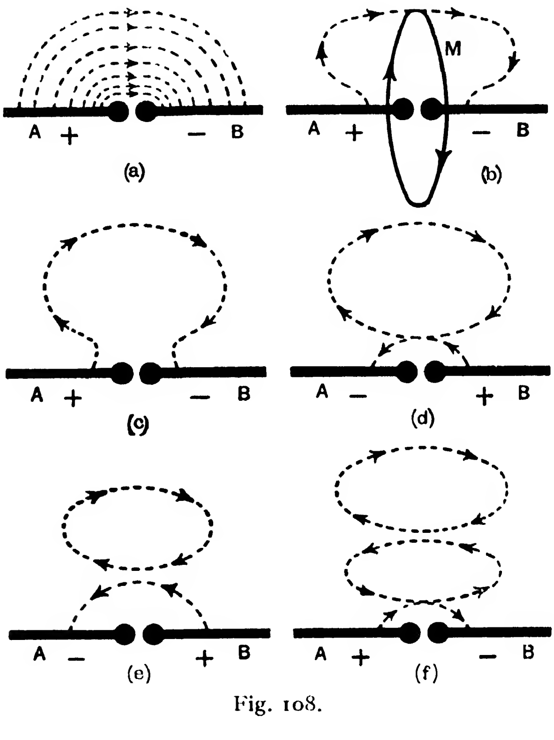


Fig. 108.

We would again emphasise a fact mentioned in Art. 3. Near the spark gap of the preceding figures the two disturbances—electric and magnetic—are not in phase, and energy pulsates in and out. A quarter of a wave length away they have got into step—the one is a maximum when the other is a maximum—and waves pass out with the velocity of light. The two disturbances are at right

angles, and the direction of propagation is at right angles to both.

Figs. 109, 110 will emphasise this point. Consider two closed loops as shown, XY being normal to the oscillator at its mid-point, and the figure representing the condition at a distance beyond the quarter wave-length distance. At points such as P the magnetic disturbance H and the electric disturbance F have their greatest values, at Q they are zero, at R they are again greatest but in the opposite

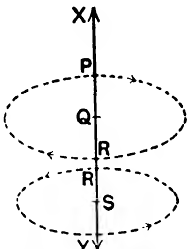


Fig. 109.

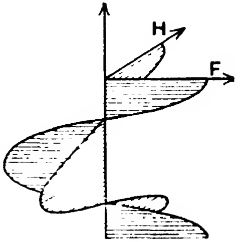


Fig. 110.

direction to P, at S they are again zero, and so on. The magnetic force H is at right angles to the electric force F, and both are at right angles to the direction of motion, but F and H are in step or in phase, both reaching their maximum and both their minimum together.

In the case of wireless telegraphy and telephony, since the lower end of the radiating aerial is earthed the loops take the form shown in Fig. 111. Again, as the earth joins the feet of these half loops, currents flow through the surface layers of the ground. The magnetic lines are shown in the lower half of the figure.

Now consider the waves of Fig. 111 arriving at a receiving aerial. As this aerial happens to join two points of the electric field at different potentials a current is produced in it. The top of the aerial being more positive than the earth end, electrons rush up from the ground and charge the aerial negatively. If the aerial is in tune with the

transmitting station it will be just on the point of discharging itself when the next half wave arrives which, of course, will help the discharge and the recharge in the opposite direction.

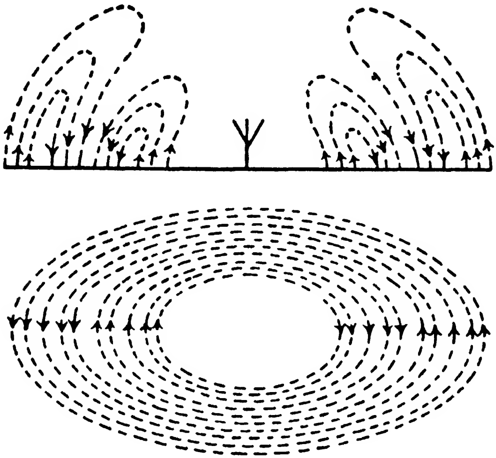


Fig. 111.

We can also discuss the effect of the waves arriving at the aerial by considering the magnetic force instead of the electric force in the wave, but we need not go into this for the conclusions arrived at are the same.

It was realised quite early in the history of wireless that if the earth were surrounded by a spherical conductor some distance away, the waves might travel between this conducting surface and the earth and might follow therefore the curvature of the earth so that, despite the earth's curvature, signals might pass right round it: and it was known that signals could do this.

Such a conductor was proved to exist and it is known as the **Heaviside layer.** Owing to the action of the sun the upper regions of the atmosphere are *ionised*, *i.e.* positively and negatively charged particles called ions (page 7) and

free electrons are produced in it and the result is that at a height of from 50-100 kilometres an upper layer of the atmosphere is produced which acts as a good conductor. The original ideas as to how this layer acts have been partly modified in recent years, but it seems to reflect waves going upwards back to the earth making long signalling distances possible. (During daylight the layer partly *absorbs*, but after dark reflection is pronounced).

We have seen that, accompanying the propagation of the wireless waves, there are currents circulating in the surface layers of the earth, the energy being derived from the waves themselves, and it is clear that the energy dissipated in this way will depend upon the surface resistance. Dry soil has a very high resistance compared with sea water, hence wireless messages can be transmitted over the sea to a much greater distance than over land. Again, since the resistance of a conductor to high frequency currents depends on the frequency, being greater the greater the frequency, the loss referred to above will increase with the wave frequency: hence from this point of view, long waves along the ground will transmit signals to a greater distance than short (ground) waves. (See pages 140, 141.)

It is a well known fact that the range of wireless signalling is greater at night than during the day. Here again, owing to the action of the sun, the lower regions of the atmosphere are to a certain extent ionised during the day which leads to a dissipation of energy and reduction in signalling distance. When the sun sets, recombination takes place between the positive and negative ions, with the result that there is less absorption, and signalling distance increases. The Heaviside also reflects best at night.

Abnormal electrical conditions in the atmosphere, *e.g.* lightning, sudden recombinations of ions, etc., affect the receiving apparatus; these are known as **atmospherics** or **Xs**, and they often prove an utter nuisance in wireless reception.

Good signals at night frequently follow a cloudy day, probably owing to the facts that the lower regions of the atmosphere have not been so strongly ionised during the day, and also that the earth's surface is moist.

Wet weather decreases the insulating properties of the aerial system, but at the same time improves the earth system. On hot, dry days the lower regions of the atmosphere are highly ionised and the earth dry and of increased resistance; hence signal strength and distance are reduced.

Signalling between two stations so situated that when it is night time in one station it is day time in the other is often difficult. This is probably due to reflection, etc., in the twilight area—the part where there is a change from dark to light—caused by irregular ionisation of the atmosphere.

Fading, *i.e.* the dying down of a signal until sometimes it can scarcely be heard and then its rise again to normal strength, is another wireless nuisance, and one explanation is as follows: The Heaviside layer, as has been pointed out, is a layer of ionised air in the upper regions of the atmosphere which is a good conductor. Now in Fig. 112 it will be seen that a receiving station R, tuned in to the transmitting station T, may be under the influence of two waves from T, one travelling direct along the earth and the other reaching R after reflection (or, more likely, gradual bending downwards), at the Heaviside layer. The former wave is more or less regular in character, but the latter, for reasons which cannot be explained here, is subjected to a certain twisting at reflection; moreover the two have travelled different distances. If these two waves meet at R in such a way that they help each other, *i.e.* if they meet as it were "crest to crest and trough to trough," the signal will be strengthened, but if they meet so as to oppose each other the signal will decrease.

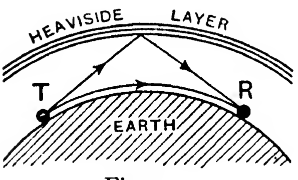


Fig. 112.

Incidentally, experiments led Appleton to suggest the existence of another layer—the **Appleton layer**– above the Heaviside, and later work indicates that this is mainly responsible for the long distance transmission of short waves in practice. And there are other similar layers.

Much investigation has recently been made on the spreading and other effects produced by these upper layers, and the results of these investigations may be briefly summarised as follows:—

(*a*) At short distances from a station reception is mainly due to the ground wave, *i.e.* the direct wave of Fig. 112: the other—the atmospheric wave as it is called—is absent.

(*b*) At medium distances during the day the ground wave is the more effective as far as the ordinary broadcasting band of waves is concerned: in comparison, any atmospheric wave is weak owing to its extra loss of energy caused by the ionisation of the lower regions in the daytime: at night the atmospheric wave comes in almost as strong as the ground wave and " fading " effects may appear.

If the waves are *short* they may have such a high frequency that those going upwards may not be sufficiently bent down by the Heaviside layer to reach the earth. In Fig. 113, for example, the waves (1) are not sufficiently bent to reach the earth, but (2), which reach the layer further from the vertical, are: thus the ground wave is effective near the station S but being a short wave is quickly absorbed and disappears at X: from X to Y no signal is heard and then the atmospheric waves (2) are effective. XY is called the **skip distance.** Of course waves (1) will probably be reflected by the Appleton layer and, owing to the greater height of this layer, come down at a greater distance from S.

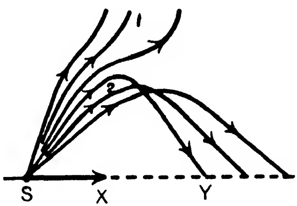


Fig. 113.

(*c*) At great distances the ground wave may be absent and reception due entirely to the atmospheric wave.

Much work has also been done in connection with " **wireless echoes,**" as they are called. Thus a " dot " signal is received from a station and then $\frac{1}{7}$ of a second later another signal is heard: after another $\frac{1}{7}$ of a second another signal is heard, and so on. These are due to

waves travelling right round the earth and, so far, waves which have travelled 2½ times round have been recorded. Signals about *half a minute* after the first have also been noted: the explanation is probably that the wave has passed through the Heaviside and Appleton layers, gone on for many miles, and then been reflected back by electrons emanating from the sun.

In reading about wave lengths, tuning, etc., the term **sidebands** will often be encountered. Each broadcasting station is given a certain wave length (and therefore frequency) for its carrier wave and is told to keep to it with a view of preventing interference with other stations. Now we can write down a mathematical equation which represents a certain carrier wave and then we can show that when the carrier wave is modulated by, say, a note of a certain frequency, the equation which represents the modulated wave really consists of three parts, an equation still representing the carrier wave and two others—known as *sidebands*—one representing a bigger frequency wave and one a smaller frequency wave than the carrier, the actual frequencies depending on the frequency of the modulation. When we consider the complex modulation due to, say, an orchestra or even the human voice, it will be clear that whilst each station must have a fixed carrier wave length and frequency a certain sideband allowance must be given below and above the station frequency, and the present spacing between stations on this account is nine kilocycles frequency. This has been referred to in dealing with condensers (page 68) and will be referred to again later.

There is one more point we will mention, for you may meet it in your reading: to *understand* it thoroughly demands a knowledge of physics and mathematics beyond this book, so do not worry about it. It is in the sidebands really that we have the properties of the words spoken, and large commercial telephone companies often use a method of transmission by which the **carrier wave is suppressed**, *i.e.* not transmitted from the transmitting station to the receiving station but is supplied again at the receiving end: sometimes also they suppress one sideband. This

results more or less in *secrecy*, for the signals are really unintelligible until a correct oscillator at the receiver puts things complete again. The method is used in the Rugby to New York wireless telephony transmissions. It is of no use in broadcasting.

From what has been said in this chapter you will be prepared for the statement that light waves and wireless waves are identical in general character. They are both waves in the aether and they both travel with a velocity of about 186,000 miles per second. They differ only, in fact, in frequency and wave length, light waves being of greater frequency and shorter wave length than wireless waves.

And there are other aether waves also of the same general character but differing in wave length. The shortest aether waves known are the "penetrating radiation" which has recently been shown to reach the earth from above, and their wave length is about ·00000000000005 metre. A little further down the scale of increasing wave lengths come the Gamma rays from radium, etc., and then the X-rays. Further down still comes the ultra-violet rays, then the light waves of length ·00000043 metre (violet) to ·00000075 metre (red), and then the infra-red. Further down still come the short wireless waves, then the broadcasting band (say, 200 to 600 metres), and then the long wireless waves. Lower still we have the waves from an ordinary alternator in a power station: but the frequency here is only about 50, so that the length of the waves is about 6,000,000 metres or 3720 miles.

In the chapters which follow, we will first deal further with the *reception* of "wireless" since this is the part in which you are naturally most interested: more about the "sending end" will be given in Chapter XII.

CHAPTER VII.

RECEIVING AERIALS AND EARTHS.

1. The Outdoor Aerial.

The aerial is a most important feature in the ordinary wireless receiver, and every effort should be made to erect the best possible which circumstances allow. In this chapter we will deal with the aerials suitable for the *usual* reception (medium and long waves). Special aerials for short and ultra short waves, directional work, etc., and aerials to eliminate interference are referred to later.

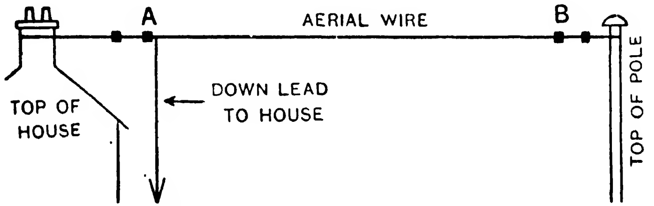


Fig. 114. The small black squares denote insulators.

For the receiving sets ordinarily in use an outside aerial is always more efficient than an inside aerial.

Stranded wire is best, for it has good mechanical strength and also offers low resistance to the high frequency currents; a low resistance aerial means, of course, less waste of energy in the aerial itself. The usual material is copper, and the gauge known as $\frac{7}{22}$, *i.e.* the variety consisting of 7 strands of No. 22 S.W.G. copper wire, is largely used. It should be enamelled to prevent corrosion.

Two of the most common types of receiving aerials are known as the **inverted L type** and the **T type** respectively. In the former (Fig. 114) one end of the wire is supported by a mast or tree or another building, and the other end of the wire by some suitable point on the house in which the receiving set is used: a "down lead" (also of $\frac{7}{22}$ copper wire) joins the end of the horizontal portion to the receiving

set inside the house. In the **T** type the down lead is taken from the *electrical centre* of the horizontal portion: if this portion is truly horizontal the electrical centre is the mid-point, but if one end is higher than the other, the electrical centre is nearer the lower end.

The aerial, as has been indicated, forms part of the receiving set, and we have seen that the set, by means of inductances and condensers, must be "tuned to resonance" with the arriving waves. Now the aerial portion alone has its *fundamental or natural wave length* (which of course differs with different aerials) and would pick up signals, if used without any tuner, of the same wave length as its own natural wave length. If an **L** aerial and a **T** aerial be of the same horizontal length, the natural wave length of the **L** aerial will be double that of the **T** aerial.

By the Post Office Regulations the total length of the horizontal portion together with the total length of down lead must not exceed 100 feet. For the main broadcasting band of wave lengths this was found to be, on the whole, a suitable general working value: but with modern receivers and conditions *less* is often preferable—70 or 80 feet.

The question then arises as to how much of this total is best devoted to the horizontal portion and how much to the vertical portion, and in considering this it must be remembered that two results are desired in a wireless receiver, viz. **good signal strength** and **selectivity.** If an aerial and set are lacking in selectivity and if the set is tuned to receive waves, say of 300 metres, then not only will it be necessary to make a fairly large change in the tuning devices in order to cut out these signals, but a transmitting station operating on a different wave length may produce interference. On the other hand, if the set is very selective, then not only will the slightest change in the tuning devices cut out the signals being received, but stations operating on a different wave length will not interfere.

Now it is found that if the length of the aerial be reduced step by step the selectivity increases, but the signal strength somewhat decreases, and in practice a compromise must

be made. From theoretical considerations it can be deduced that for satisfactory results the height of the ordinary receiving aerial should be as great as possible up to about 60 feet, the balance being in the horizontal portion, and this has been verified experimentally. *Height is thus a primary consideration.* An aerial 37 feet high and 63 feet long is better than one 20 feet high and 80 feet long.

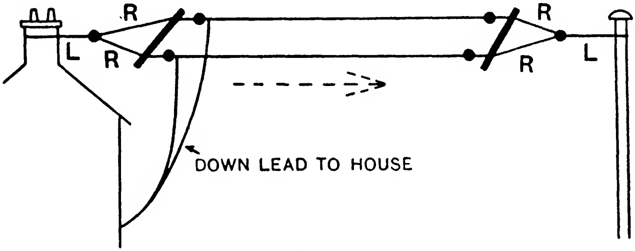


Fig. 115.

The aerial should be kept well away from surrounding objects such as intervening trees and roofs of buildings, for these not only reduce the effective height but they absorb energy from the waves and thus exert a "screening" effect on the aerial: they also re-radiate energy. If telephone or telegraph wires are in the vicinity it is best to arrange that the aerial is at right angles to them if possible.

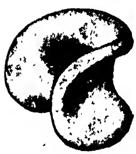


Fig. 115 (*a*).

In some cases a **twin wire** aerial (Fig. 115) of either the inverted **L** or **T** type is employed, especially if the space available is unusually short. The wires should be from 4 feet to 6 feet apart, being kept at this distance by wooden **spreaders.** An insulator is fixed to the exact centre of the rope R and the lanyard L is attached to this insulator.

For ordinary reception purposes, however, single aerials are to be preferred in most cases.

It is essential that the aerial should be thoroughly insulated to prevent leakage of current. Two or three

porcelain shell insulators should be used at each end, these being from 8 inches to 12 inches apart according to the space available (Figs. 114, 115, 115 (*a*)). Other types of insulators may be used.

In the case of twin aerials the usual method of insulating is as indicated in Fig. 115. (Two insulators at each end of each wire are of course intended, but only one is shown for simplicity in the figure.) Referring to Fig. 116, however, it will be seen that the two insulators A and B form a parallel arrangement, whilst in Fig. 117 they form a series arrangement. The total resistance to leakage of current is therefore *greater in the second arrangement.* Hence some experimenters combine the two methods. The method of Fig. 116 is, however, quite satisfactory if precautions be taken.

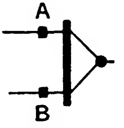


Fig. 116.

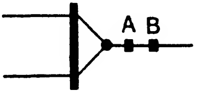


Fig. 117.

The down lead of Fig. 114 starts from the insulator A and should be *continuous with* the horizontal portion AB, *i.e.* the one aerial wire should be knotted or otherwise secured to A, one portion of the wire thus forming the horizontal and the other portion the down lead. In the case of the twin aerial, down leads are taken from each and then soldered together so as to constitute a single lead into the house (Fig. 115). It is necessary that the down lead should be kept at least 3 feet from the building—the more the better—throughout almost the whole of its length.

The end of the down lead should be attached to a long insulated " lead-in " passing through a hole in either the window frame or the wall, and preferably vertically below the aerial if this is possible. The lead-in tube should be thick and should project at least four inches—*more if possible*—at each side of the wall. Inside the room, the receiving set should be placed as near to the lead-in as convenient, so that the connection between the lead-in and the aerial terminal of the set may be as short and straight as possible.

In all cases, as a protection against lightning, it is wise to use an earthing switch fixed to the wall or window *outside the house.* In this case the down lead, instead of being taken direct to the lead-in, is taken to the terminal A (Fig. 118) of the switch; terminal S is joined to the lead-in, whilst E is joined to earth. When the switch arm is turned to S the aerial is joined to the set: when it is turned to E the aerial is disconnected from the set and safely earthed.

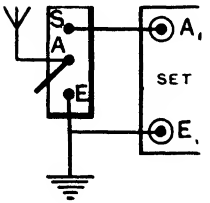


Fig. 118.

2. The Earth System.

A usual earth for most receiving sets consists of a metal plate about 2 feet square, buried either vertically or horizontally to a depth of 3 feet or 4 feet immediately beneath the aerial and near the house. The earth lead from the set should be heavy gauge, and insulated, and should be as short as possible. An insulated lead-in passing through another hole in the wall or window frame must be used just as in the case of the aerial. The earth wire must be soldered to the metal plate. Incidentally, terminal E of the earthing switch referred to above may be joined to this same earth plate.

The soil in the vicinity of the plate must be kept damp. To secure this it is usual to fix one or two vertical tubes, the sides of which are preferably pierced with holes, over or near the plate, their upper ends projecting above the ground. In dry weather water can be poured down these tubes and the soil immediately surrounding the plate kept moist. Several "earth tubes" based on this principle are now obtainable. Two or three buried plates or earth tubes all connected together may be used if a greater surface of metal exposed to the soil is desired.

If a *main* water pipe or tap is suitably situated near the earth lead-in, the earth wire may be attached to it either by soldering or by means of a clamp: a pipe or tap merely joined to a cistern, or a gas pipe will not do.

A really good low-resistance earth is *essential*, and many special earthing arrangements are now available. The "Ronnie" earth tube, for example, is a heavy gauge low-resistance copper tube, pierced with holes and containing a special mineral compound: the top of the tube is funnel-shaped and open to the atmosphere. The compound attracts moisture from the air and the adjacent ground, and this permanent dampness and inherent low resistance ensures a very low-resistance earth. The mineral compound can also be obtained separately and placed in the adjoining soil. One (or two) of these tubes used in conjunction with the compound makes a wonderfully efficient earth as our own tests on them have proved. A similar arrangement is the "Percolite," which also makes an excellent earth.

Another earthing method is that sometimes referred to as the "capacity earth." This consists of a good stout bare wire equal in length to the aerial laid along the ground exactly underneath the aerial, the far end being soldered to a metal peg about 3 feet long driven well down into the ground. Sometimes a modification is made, the wire being laid about 6 inches below the surface of the ground throughout its whole length. A still better arrangement is to use, say, three buried wires, one under the aerial and one on each side parallel to, and from 4 feet to 6 feet away from, the central wire, the three being joined together at the house end and a lead taken thence to the receiver.

3. The Balanced Aerial or Counterpoise.

Instead of the usual earth the **balanced aerial** or **counterpoise** arrangement may be adopted. The method where a single wire aerial is employed is indicated in Fig. 119. In the figure C is a wire of the same length as the aerial A, situated vertically beneath it at a height of 6 or 7 feet above the ground, and insulated and supported in the same way as the aerial itself: from the house end of C a lead passes in the usual way to the earth terminal of the receiving set.

The counterpoise both for transmission and for reception has many supporters, particularly for medium and short waves. For reception purposes in private houses it is not so convenient to arrange as the earth plate system, but cases of poor reception, particularly as regards selectivity, have been known to be improved considerably by its adoption.

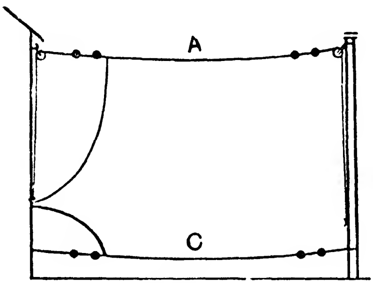


Fig. 119.

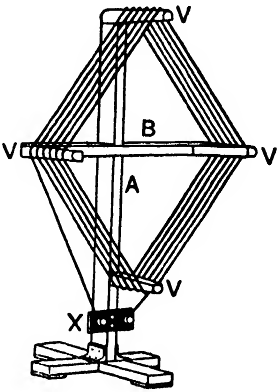


Fig. 120.

4. Indoor Aerials.

Some people, *e.g.* dwellers in flats, are unable to erect an outdoor aerial and in such cases an **indoor aerial** must be resorted to. A good type is easily constructed as follows:—

To the wall or picture rail at one end of a room three hooks are fixed, and to each hook a piece of string is attached, the other end of each string carrying an insulator: the hooks should be about 4 or 5 feet apart. This is repeated at the opposite wall of the room. A length of aerial wire is then fastened to the central insulator at one wall, carried across the room and attached to the central insulator at the other wall, the remainder of it forming a down lead to the set. Similarly two aerial wires are stretched across the room between the other insulators, the down leads of these being attached to the central down

lead and soldered, thus giving the **V** formation and single connector to the set after the manner indicated in Fig. 115. Many other arrangements, *e.g.* an insulated wire 20 feet long above the picture rail, one end being taken to the set and the other left " free," are in use.

Within a distance of a few miles from a main broadcasting station the aerials described above will give satisfactory results. For greater distances the results are, in a general way, about 30 to 40 per cent. of what an outdoor aerial will give.

5. Frame Aerials.

With powerful valve receiving sets what are known as **frame aerials** may be used. One form—the **box type**—is depicted in Fig. 120. To a suitable wooden base a vertical bar of wood A about 4 feet 6 inches long is fixed, carrying at a point 3 inches above its centre a horizontal bar of wood B about 4 feet long. Attached to each end of B and to the top of A are short rods of vulcanite V, each provided with six saw cuts at least $\frac{2}{5}$ inch apart: a similar piece of vulcanite V passes through a hole in A 6 inches from the bottom as indicated. X is a piece of vulcanite fitted with two brass terminals.

Six turns of bare or insulated copper wire of 18 to 26 S.W.G. are wound continuously on the frame, the beginning of the wire being fixed to one terminal on X and the end to the other terminal on X. These terminals are joined to the aerial and earth terminals of the receiver when the set is in use. The dimensions given are suitable for the usual broadcasting: for long waves more turns of wire will be advisable.

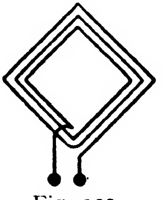


Fig. 121.

Another type of frame aerial is the **diamond type.** This somewhat resembles the box type in general appearance, but the winding is a flat coil, *i.e.* all the turns lie on one vertical plane, as roughly indicated in Fig. 121.

The frame aerial is what is called **directional** in its reception, *i.e.* it responds to signals when it is placed in one

position with regard to the incoming waves, whereas it does not respond when placed in another position. It can be shown that for a maximum current to flow in the aerial, the plane of the frame (or the bar *B* in Fig. 120) must be pointing towards the transmitting station (Fig. 122 (*a*)): if the frame be turned through an angle of 90° so that the plane of the frame is, so to speak, broadside on to the station, *i.e.* at right angles to the direction of the station (Fig. 122 (*b*)) the reception is a minimum. The box aerial has better directional properties than the diamond aerial. Obviously in working with a frame aerial it must be slowly rotated until the signals are at their maximum strength.

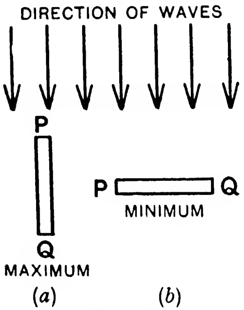


Fig. 122.

"Portable" wireless receivers employ some form of frame aerial which is inside the containing cabinet.

Incidentally it may be mentioned that the ordinary outdoor aerial, say the inverted L type, has directional properties to a certain extent. It gives preference to signals coming at its "nose" or lead-in end, as indicated by the arrow in Fig. 115; in practice this is negligible.

In the preceding pages we have given you the main points about aerials and earths which are used in the majority of cases of ordinary wireless reception at home. In transmitting stations bigger and more complicated arrangements are naturally used. Special aerials have also been devised for directional transmission and reception particularly for ship and aeroplane navigation, and yet another type is used for the "beam system" for directional communication with the Dominions. Special aerials are also used for short wave broadcast reception (say 13-150 metres) and for television (ultra short waves 3-10 metres) and yet other types are designed to eliminate interference due to electrical machinery. We will refer to all these later.

CHAPTER VIII.

THE CRYSTAL AND THE VALVE.

1. Crystals.

In a general way we can divide crystals into two classes, viz. (1) those which require a fine metal contact (called the "catwhisker" type) and (2) those which require another crystal in contact with them (known as the "perikon" type). In the first class are silicon, iron pyrites, carborundum, galena, etc. In the second class are zincite, bornite, copper pyrites, etc.: galena can also be used as a perikon.

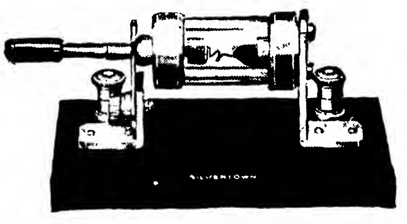


Fig. 123.

Some crystals in the first class work best with certain metal contacts. Carborundum and silicon work best with steel; iron pyrites works best with gold: galena works almost equally well with gold, silver, copper, or brass. Of the second class, zincite with bornite, and zincite with tellurium give very good results.

There are numerous types of "crystal detectors" (strictly *rectifiers*). In one form a small brass cup fixed at one end of a glass tube contains the crystal, which is held in the cup by screws or is fixed therein by Wood's metal (which melts at a low temperature). At the other end of the tube is a rod carrying a fine wire—the catwhisker—and this rod can be moved to and fro or rotated so that the catwhisker can be put gently in contact with different points of the crystal surface. The cup and the

rod are joined to the two terminals of the detector. A typical crystal detector or rectifier is shown in Fig. 123.

Many "permanent" detectors are in use. These are merely some form of the above, but permanently fixed in a sensitive position so that no adjustment is necessary.

Carborundum requires a small voltage to be applied to it—about ·6 volt—by a small battery and potentiometer arrangement (variable resistance).

2. The Thermionic Valve.

Valves are now almost universally used in radio reception, and for the very simple reason that they can do certain things better than any other piece of apparatus we know of, and the real reason they can do this is that they have a tremendous supply of electrons: these electrons are given off by a hot filament, rather like the filament of an electric lamp, inside the valve. There is no air in the valve.

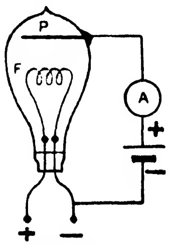


Fig. 124.

One of the earliest kinds of valves was called the **diode**, and it is shown in Fig. 124. It consists of an ordinary **filament** electric lamp—the filament is marked F —fitted with a metal plate P which is called the **plate** or **anode** of the valve.

When the filament is heated by passing a current through it from, say, an accumulator joined to the points marked + and —, the heated filament gives off (negative) electrons; hence if P be kept positive by joining it to the positive pole of another battery, shown on the right, the negative electrons from F will be attracted towards the positive plate P. But electrons moving from F to P means, of course, that an electronic current is going from F to P (and this can also be worded "a conventional current is going from P to F"), and so the indicating instrument A will be deflected.

If the battery connections be reversed, the negative pole being joined to P, the current *through the valve* will stop, for P being negative repels the electrons from F, so that

they cannot get across. If an oscillatory pressure be used instead of a direct pressure from a battery, current will flow through the valve when the plate P is positive but not when the plate P is negative.

You will see, therefore, that the *diode* valve may be said to be like the crystal in the sense that a current can only flow through it in one direction. You should note particularly that *in order to get a current through* A *and the valve, the positive pole of the battery must be joined to the plate:* a current in this circuit is spoken of as the " plate current " or " anode current."

Now before going further you should grasp thoroughly the above idea. Remember that—

(1) When the accumulator is joined to the ends + and − of the filament a current passes *through the filament* and it gets hot. This current is a movement of electrons through the filament from − to +, but the rushing, jostling, bumping of electrons is so great in a hot filament that many are thrown out of the hot filament into the space near it.

(2) When P is joined to the positive of the other battery on the right it pulls these electrons towards it. This would mean, of course, that P in time would become negative, but by joining the negative of the battery on the right to the filament we provide a complete road for the electrons. Thus we now have a *plate current*, consisting of a movement of electrons through the valve from F to P, thence to the battery on the right, and from the battery back to F. This plate current works the instrument A.

The electrons are given off by the hot filament, and the higher the temperature the better will they be given off. One of the best materials to use is *tungsten*, and if this is used alone for the filament the valve is called a **bright emitter valve.** If certain other substances, *e.g. barium oxide* or *thorium oxide* are added to the tungsten we get the electrons given off at a much lower temperature; such a valve is called a **dull emitter valve,** and they are now mainly used. The number of electrons given off per second is enormous—several times a million times a million. The speed of the electrons is also enormous.

Now the ordinary valve which you use with your wireless receivers to-day is known as a **triode.** It has a filament F and a plate P, but it also has a wire **grid** G between them, the three being quite separate from each other (Fig. 125). Let the plate and filament be joined to a battery (from 30 to about 200 volts in ordinary cases of wireless receivers) so that electrons are passing from filament to plate and therefore the (conventional) plate current from plate to filament. We are assuming of course that the filament is heated by an accumulator or other battery (not shown in Fig. 125).

Imagine now that the grid G between P and F acquires from some outside source a negative potential. It will repel the electrons coming from the filament and stop many of them from reaching the plate; hence the plate current will decrease. If the potential of the grid becomes positive it will attract the electrons from F, and (as P is at a higher potential in practice), many continue their motion through the grid holes to the plate; thus the plate current will increase: the grid really does the work and the plate gets the benefit.

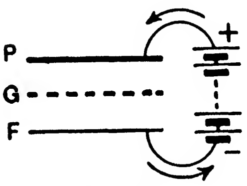


Fig. 125.

To summarise—*lowering the grid potential reduces the plate current: raising the grid potential increases the plate current.* You will thus see that by varying the potential of the grid we can vary the flow of electrons through the valve from F to P, and therefore vary the plate current.

Fig. 126 will show this better and more exactly. To get this curve you would have to give the grid a certain potential and measure the plate current. Then you would have to give the grid a different potential and again measure the plate current, and so on. Then you would plot the curve, marking grid potentials along the horizontal and plate currents along the vertical. Potentials to the left of O are negative and potentials to the right of O are positive.

Now when the grid has the negative potential OB it repels all the electrons from F, and there is no "plate current." As the potential of the grid rises to zero (O), *i.e.* becomes *less negative*, the plate current increases, as shown by the curve, to the value OA. As the grid potential becomes more and more positive the plate current rises more and more according to the curve ACD. A curve of this kind is called a **characteristic curve of the valve**: you will see many such curves in valve manufacturers' advertisements.

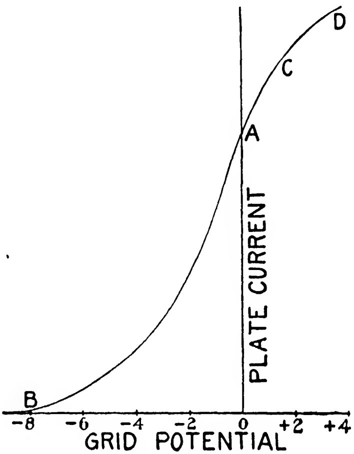


Fig. 126.

Now here is another important point about valves. Although the electrons inside the valve move at such a tremendous speed their mass is so small that if we *suddenly* change the potential of the grid even by a small amount, we get an *immediate* change in the stream of electrons, *i.e.* in the plate current—there is absolutely no waiting. We will come to the action and uses of the triode in wireless receivers presently.

Another type of valve is also in use, especially for what is known as *high frequency amplification* (*i.e.* amplification or magnification *before* rectification—see Chapter XI.), and it is referred to as the **screened-grid valve.** From what we told you in Chapter IV. about condensers you will quite understand that there is *capacity* between the plate and grid of a valve, and one result of this may be that too much energy may be " fed back " from plate to grid: this causes " howling " in the receiver. You will understand this better later.

The screened grid valve, however, has largely come to the rescue for this defect. It is specially made to have a small capacity between plate and grid, and, moreover, it is provided with a *second* grid in between the usual grid and plate. This *screening grid* is kept at a *positive* potential, but at a less positive potential than the plate, and it therefore acts as a screen between the ordinary grid and the plate, and so prevents feed back. In the usual receivers it is customary to apply about 120 volts to the plate and about 80 volts to the screening grid. Sometimes the plate and screening grid are joined to the same pole of the battery, but a resistance is connected to the screening grid so as to "use up" so to speak the 40 volts thus making this grid's potential the necessary amount less than the plate potential. Fig. 127 shows diagrammatically the arrangement where P is the plate, SG the screening grid, G the ordinary or controlling grid, and F the filament. Note that it is used essentially for high frequency amplification. (It can be used as a detector.)

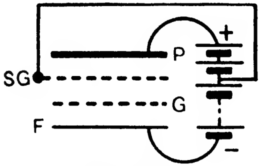


Fig. 127.

Such a valve as the above is best suited to handle small voltage changes on the ordinary grid (small grid swings) such as occur in high frequency amplification where they come direct from the aerial, for the characteristic curve of the valve is steep and it has therefore a big magnification as will be seen presently: if large voltage changes were applied to the grid the plate voltage would swing up and down so much that it might reach a value smaller than the voltage on the screening grid, and this grid might then begin to pull electrons away from the plate. This trouble may arise if it is used for what is called *low frequency amplification* (*i.e.* amplification or magnification *after* rectification—see Chapter XI.), where larger voltages are being handled. To overcome this another valve has been put on the market called a **pentode valve.** The pentode

has another grid in between the screening grid and the plate, and this grid is joined to the negative of the filament: it therefore tends to repel back again any electrons which try to get from the plate to the screening grid. Fig. 128 shows diagrammatically the arrangement of the pentode valve: while originally used for low frequency amplification it is also used for high frequency amplification and "detection."

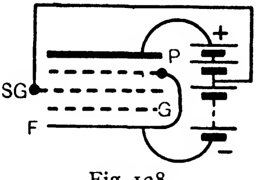


Fig. 128.

A modified screened-grid valve for *high frequency amplification* has been put on the market and it is known as the **variable mu screened-grid valve.** (You will understand the meaning of "mu" presently). With the ordinary screened-grid valve it sometimes happens (only *rarely*, however), that we get a peculiar trouble called **cross-modulation.** Thus the valve may be taking the carrier wave of one station and its programme, and then it may lift the programme of a near-by station on to this carrier wave, so that it passes on to the next valve the correct carrier wave with *both* programmes: if the correct carrier and programme stop due to the wanted station closing down, the other programme also stops though its station be still working.

This defect is due to the valve becoming overloaded and is really an effect of its small grid swing. The variable mu pattern overcomes this by a slight change in its construction, viz. its grid is spaced irregularly: but this slight change gives its characteristic a more gentle incline, so that we can give the grid a bigger negative bias and therefore allow it to have a larger grid swing, *i.e.* larger potential changes. In fitting the variable mu to a receiver we must make arrangements whereby a varying bias (negative) may be put on the grid: the usual method is to put a variable resistance (potentiometer) across the grid battery and to tap this potentiometer to the grid. The varying bias which this valve can take is largely used in controlling volume.

Wireless receivers are sometimes run off the electric light mains, thus dispensing with batteries—either high tension (which supplies the plates) or low tension (which heats the filaments) or both—and valves have been specially constructed for the purpose. These are spoken of as **mains valves** and they may be triodes, screened grids, or pentodes.

If the supply is alternating current it is changed to direct or continuous current for the high tension or plate supply: for heating the filaments alternating current can be passed through them if special filaments are employed, but the more usual method is to pass the alternating current through a " heater " inside the valve which radiates heat to the filament or cathode, *i.e.* the cathode is heated indirectly. In one type of valve for this purpose the cathode (or filament proper) is a nickel tube coated with a mixture of barium and strontium oxides which operates at a dull red heat: it is heated by means of a hairpin of tungsten (placed inside the tubular cathode but insulated from it by porcelain), through which the alternating current passes. The A.C. supply voltage must be cut down to the required voltages for the filaments and plates by means of transformers.

If the house supply is direct current the voltage must be cut down to the required values for the plate supply and filament supply by means of suitable resistances. In all cases smoothing devices—consisting of inductances and condensers—are also used to prevent any changes in the supply voltage, causing a hum in the receiver.

The devices for carrying out the above are incorporated in the set if it is an " all mains " receiver, but you can purchase them separately (" eliminators " or " mains units ") if you wish to convert your battery driven set into an " all mains ": you can also purchase a mains unit to dispense with your H.T. (dry battery), and also use it to charge the accumulator [L.T.). See Chapter XI.

You will note that the *diode* is a two " electrode " valve (plate and filament), the *triode* a three electrode, the *screened-grid* a four electrode, and the *pentode* a five electrode. The triode is the one you know best, and we

will deal with it in our further explanation of valve actions.

3. The Two General Uses of a Valve in Wireless.

We will now set to work to examine exactly how a valve is used in a wireless receiver, and it will help you to understand this if you first take a glance at Fig. 129, which shows the general connections of a valve, etc., to a receiving aerial: we have purposely left out a few things in this figure which are actually used in a valve receiver because all we want you to do at present is to get a general idea of how a valve is joined up.

The **low tension battery** (2 to 6 volts) is shown at the bottom of the figure: it is usually one, two, or three accumulators and is used for heating the filament. The latter sometimes has a variable resistance in its circuit, called a filament rheostat, so that the current given to it can be increased or decreased. With modern valves the rheostat is not necessary, but it can be utilised for other purposes. The **high tension battery** (100 to 200 volts in practice and 500 volts and more for television) is shown on the right: its positive pole is joined to the plate of the valve, and the telephones, etc., are in its circuit. The aerial inductance is joined between the grid and the filament. You need not trouble at present about the condenser which is joined across the telephones and battery.

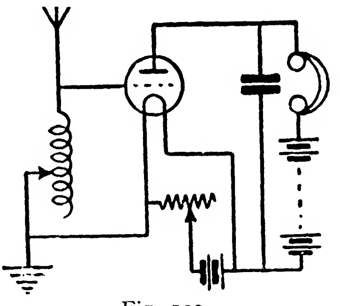


Fig. 129.

When the waves arrive at the aerial, oscillations are set up in it. We thus have rapidly changing potential differences set up at the ends of the aerial inductance on the left, and these are applied between the grid and filament. The electrons in the valve immediately respond to these

changes applied to the grid, with the result that we have corresponding changes (really magnified) in the direct current from the high tension battery in the plate circuit which, of course, cause the telephones to respond.

Now in modern receivers the valve is used in two ways, viz. (1) as a **rectifying detector**, similar to the crystal, and (2) as an **amplifier,** *i.e.* specially for amplifying or magnifying the signals so that ultimately a louder sound is produced, or more distant stations brought in. A valve used as a detector also amplifies.

Again, an amplifying valve may be used to amplify the weak signals just as they arrive at the aerial, *i.e.* before they are passed on to the detector: this is called **high frequency amplification,** for the signals are magnified at high frequency. (In ordinary wireless this helps to bring in distant stations.) A valve can also be used to amplify after the signals have passed through the detector and are rectified; this is called **low frequency amplification,** and is used to further magnify the sound in the telephones or to enable a loud speaker to be used.

4. Using a Valve for Amplifying or Magnifying.

Consider the *steepest* part of the valve curve shown in Fig. 130. Suppose the grid of the valve (when no signals are being received) to be somehow or other at a potential represented by OA. A steady plate current will be passing, represented by AF. Now suppose wireless waves arrive and oscillations are conducted to the grid. These will vary the voltage of the grid, the positive half waves causing the grid potential to be higher and equal to OB, say, and the negative half waves causing it to be an equal amount lower, *i.e.* equal to OC.

When the grid potential is OB the plate current will have increased from AF to BE, and when the grid potential is OC the plate current will have fallen to CD. Thus as the grid potential swings to and fro (due to the arriving waves) between OB and OC, the plate current swings between BE and CD, and further, the plate current changes follow

the grid potential changes, and therefore the incoming waves, no matter how rapid the changes may be.

As we are working on the *very steep part* of the curve, however, a small jump from C to B causes a big jump from D to E, and this will be more pronounced the steeper the curve. It will be seen by comparing the two curves P and Q, where P represents the potential swings applied to the grid from the aerial and Q the current swings in the plate circuit, that the swing of Q will be bigger and bigger the steeper the curve. Thus the valve has amplified or magnified the variations impressed upon the grid. In amplification the valve should be worked on the steep part of its curve (see p. 188).

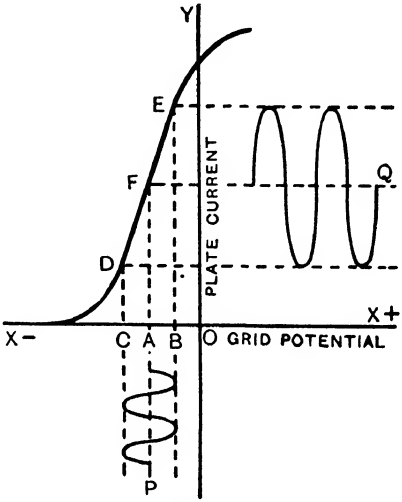


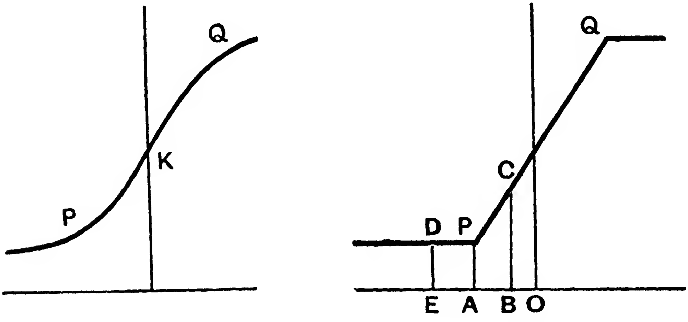
Fig. 130.

5. Using a Valve for Rectification or Detection.

Now a valve can also be used as a rectifier or detector just like a crystal. Consider, not the straight steep part, but the parts of the valve curve where the *bending* is greatest, *i.e.* the " knees " P and Q (Fig. 131 (*a*)). So that you may grasp the idea we have exaggerated these in Fig. 131 (*a*), and to make the explanation still simpler we will exaggerate them still more for a moment as in Fig. 131 (*b*).

With this curve let the grid potential be equal to OA when no waves are passing, in which case the plate current is AP. When wireless waves arrive the negative half-wave lowers the potential of the grid to OE, but the plate current does not alter—it is ED, which is the same as its original

value AP. When the positive half-wave arrives the grid potential rises to B and the plate current becomes BC. We thus get a plate current variation from AP to BC when the positive pulses arrive, but not when the negative pulses arrive. The valve is therefore responding, as it were, to swings in one direction only, just similar to a crystal. To utilise this rectifying property then, the valve must be so arranged that the bending part of the curve is used.



(*a*) Fig. 131. (*b*)

What it really amounts to is that when the negative half wave arrives lowering the grid potential from A to E it is not reproduced, as we might say, in the plate circuit, but when the positive half wave arrives raising the grid potential from A to B it is reproduced in the plate circuit: this of course is rectification.

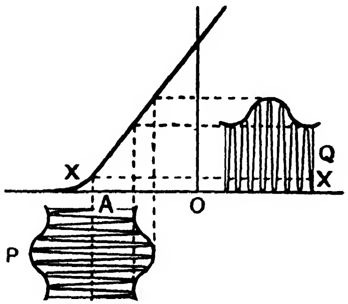


Fig. 132.

Fig. 132 shows, after the style used in Fig. 130, the rectification action we are just considering. The grid is given the negative potential represented by OA, and again we are using the

bottom bend of the curve. Here, however, we have taken a "modulated" wave as coming up to the aerial, and a corresponding pressure fluctuation being applied to the grid: this is shown at P. The resulting plate current changes are shown at Q: it will be noted that the swings Q above XX are bigger than those below XX—the latter in fact being practically wiped out—on the whole there is an increase of plate current. Note also that owing to the straight nature of the curve above the bend, the changes at Q copy those at P, *i.e.* there is, as we say, proportionality between input (P) and output (Q). Clearly similar results would happen if the upper knee (Fig. 131) were used.

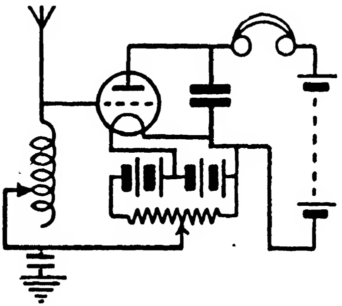


Fig. 133.

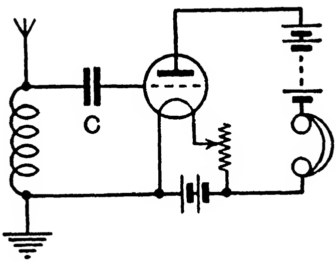


Fig. 134.

This method of rectifying by a valve is called **anode bend rectification**, and Fig. 133 shows a valve joined to an aerial circuit for this form of rectification. You will notice we have drawn four cells in the low tension battery, the filament being joined to two of these. A resistance (called a *potentiomenter*) joins the poles, and by the moving contact shown the potential of the grid to begin with may be adjusted so that it falls at the point A (Fig. 132) where the curvature is changing rapidly and where the valve must be worked for anode bend rectification.

Your wireless receiver probably uses another method known as **grid leak rectification.** It really corresponds to

getting rectification at the point K (Fig. 131) or thereabouts corresponding to zero volts on the grid, but it is much more difficult to explain to a beginner.

Look at Fig. 134. A condenser C has been put in the grid circuit: this does not stop the high frequency aerial impulses from reaching the grid, for an alternating current can " work through " a condenser. For simplicity we take the grid to be at zero potential.

Now imagine waves to be arriving at the aerial and high frequency impulses passed on to the grid. If the first half-wave is positive the grid attracts negative electrons from the filament, some of which get caught in the grid neutralising the positive there. If the condenser were absent any surplus electrons would be able to get away through the aerial inductance, but they cannot do this on account of C, and so they stay on the grid lowering the grid potential.

The next half wave is negative and still further lowers the potential of the grid though not attracting electrons from the filament. The next half wave is positive and the grid again draws electrons from the filament; so the process goes on, the grid becoming more and more negative and its potential falling. As the grid potential falls the plate current, as we have seen, also falls, *i.e.* the plate current varies in the downward direction when the waves arrive, but it does not vary in the upward direction, and this, of course, indicates a " rectification action."

Now let the two coatings of C be joined by a high resistance R of one or two million ohms (called a **grid leak**) as shown in Fig. 135. This leak opens out a road from the grid to the filament *via* the aerial inductance, along which the accumulated electrons can escape from the grid when the latter has acquired a certain charge of electrons and is therefore at a certain negative potential. This escape of electrons brings the grid back to its original condition ready for the next train of waves.

It will be seen, therefore, that each time a *group* of oscillations is received in the aerial the grid is left with a negative potential (and the plate current decreases in step

with this) which gradually returns to its normal value, the accumulated negative electrons escaping through the leak when the (negative) pressure behind is sufficient to drive them through the leak resistance. The effect of this cumulative variation of grid potential is to produce a corresponding variation in the plate current, and it is a low frequency or audible effect: thus telephones can be used in the plate circuit.

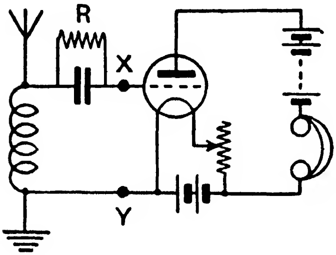


Fig. 135.

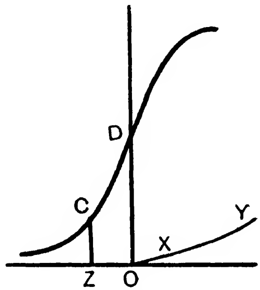


Fig. 136.

It will be apparent, too, that in grid leak rectification there is a *decrease* in the mean plate current when a signal is received, whereas in anode bend rectification there is an *increase* in the mean plate current as previously indicated.

Perhaps the following will make the grid leak method clearer. We have seen that if the grid potential is raised above the potential of the filament it begins to attract electrons from the filament and we have a " grid current," *i.e.* an electronic flow from filament to grid. Thus in Fig. 136 we have drawn, not an accurate, but a rough valve curve, and for simplicity we are assuming that the grid current commences when the potential of the grid rises above 0 (zero): it gradually increases as the grid potential is raised, and this grid current is indicated by the curve XY. (The curves for an actual modern valve are given later.)

Now with our condenser in circuit, suppose we start to work our valve at the point D so that O denotes the grid potential, and the plate current is DO. Let waves now

arrive and oscillations be applied therefore to the grid. When a negative half passes on to the grid it becomes negative, the potential of the grid moves to the left of O (say, to Z), and the plate current falls, say, to ZC. When a positive half arrives tending to move the grid potential beyond O to the right, the grid current comes into action, *i.e.* electrons flow from the filament to the grid wiping out the effect of the positive pulse and again charging the grid negatively, and owing to the condenser this charge remains on the grid. *Thus the grid potential does not rise above* O owing to this grid current effect, and the plate current does not rise above D: that is the received oscillations cause the plate current to come downwards below D and to vary below D, but not to move upwards above D, and the valve is acting as a rectifier. We might say, in this case, that the negative half of a grid oscillation is reproduced in the plate circuit, but not the positive half; which means rectification. The grid leak allows the accumulated charge on the grid during an incoming group of oscillations to drain away so that the grid returns to its normal potential ready for the next group.

If the detector valve in this method of rectification has another valve in front of it the leak is connected, not across the condenser, but between the points X and Y in Fig. 135: this is so that the condenser C may protect the grid of the detector valve from the high potential plate of the preceding valve (due to the high tension battery) which it could not do if R were joined across it. This will be understood from the valve circuits given later.

You will often come across the expression **power grid detection.** The arrangements for this are just the same as for the grid leak and condenser method but the plate voltage must be at least 120 volts and even up to 350, and smaller grid leaks and condensers are used: it really means working on a different part of the valve curve. It will *handle* big volume without distortion and is suitable for use near a powerful station or when preceded by screened grid HF amplifiers.

6. Distortion due to Over-biasing and Under-biasing an Amplifying Valve.

Distortion in a wireless receiver is often due to the amplifying valve not being worked at the correct place on the steep part of its curve. Most modern amplifying valves require the grid to be at a certain negative potential (*i.e.* to be given a certain *negative bias* by a grid battery) when no signals are passing in order to ensure that it works on the proper part of the curve for pure amplification. *This is indicated by the makers.* If the negative bias be either too much or too little *distortion* may result.

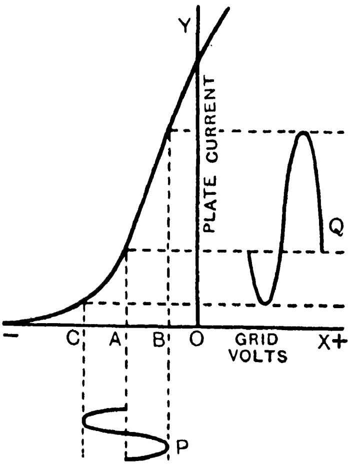


Fig. 137.

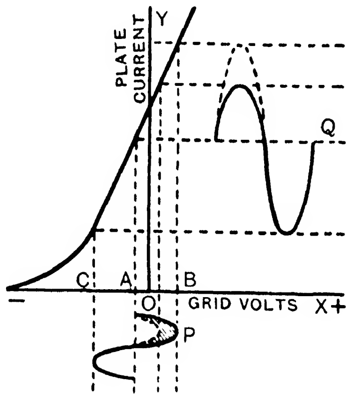


Fig. 138.

In Fig. 130 the negative bias OA given to the grid as the starting point is quite all right, and we get pure amplification. But suppose we give the grid *too big* a negative bias OA as shown in Fig. 137, thus working our amplification rather too close to the bottom knee. We now get a little rectifying effect coming on, and it will be seen that the lower swings of the plate current Q are less than the upper swings: we have over-biased (negatively) our grid, got so low down the curve that the effect of the knee (anode bend

rectification) has come in, and instead of pure amplification we are getting a certain amount of distortion.

Again, suppose we give *too little* negative bias OA as shown in Fig. 138 so that when the grid potential swings to the right the grid becomes positive, and at a higher potential than the filament: here the grid current comes on as explained in grid leak rectification and the corresponding upward plate current swings are less than the swings in the downward direction. We have under-biased (negatively) our grid and are getting distortion.

You will see, therefore, that it is essential to work the amplifying valve on the correct part of its curve so that neither anode bend nor grid rectification effects may creep in and cause distortion.

7. Some Valve Quantities.

(*a*) We have seen that a change in the voltage applied to the grid causes a change in the plate current. A change in the voltage of the plate itself also causes a change in the plate current. A certain change in the grid voltage would, however, in most cases produce a bigger current change than an equal change in the plate voltage would produce.

If a small change of x volts on the grid causes a certain change in plate current and a change of y volts on the plate causes the same change in plate current, then y is invariably bigger than x and the ratio of y to x is usually taken (although not strictly accurate) as the **amplification factor** of the valve: it is generally denoted by the symbol μ (mu), and with modern valves may be as high as 50: it even reaches 350 or thereabouts with screened grids.

(*b*) If a small change x in the potential of the grid produces a change c in the plate current the ratio of c to x measures what is called the **mutual conductance** of the valve: it is really the rate of change of plate current with change of grid potential.

(*c*) If a small change y in the potential of the plate gives a change c in the plate current, the ratio of c to y measures

what is called the **plate (or anode) slope conductance**: it is therefore the ratio of the change in plate current to the change in plate voltage which produces it.

(*d*) The reciprocal of the preceding, *i.e.* the expression $\frac{y}{c}$, is the **plate or anode slope resistance**, but is more often called the **impedance** of the valve (and denoted by R_a), although the term is not a good one: another name for it is **differential resistance.** From the definitions given above it follows that

$$\text{Mutual Conductance} = \frac{\text{Amplification Factor}}{\text{Impedance}}.$$

These quantities can be obtained from the valve curves. Fig. 139 gives the actual curves for a Mullard PM256A valve. Suppose we are at the point C with plate volts 100 and grid volts − 10. We can change the plate current by an amount CB (by 30 milliamperes) either by raising the plate voltage to 150 and keeping the grid at − 10, or by keeping the plate at 100 and altering the grid potential so that we run up the curve to E, *i.e.* altering the grid potential by CF, *i.e.* by an amount equal to CD: the amplification factor is therefore 50 ÷ CD.

Again, suppose we are at D and, keeping the plate volts at 150, we raise the grid volts to C. The plate current sweeps up to B, *i.e.* changes by an amount CB; then CB/CD indicates the mutual conductance. CB is in milliamperes and CD in volts, so that the mutual conductance is given as milliamperes per volt, or as the makers put it, mA/volt (*e.g.* 2 mA/volt).

The impedance is equal to the amplification factor divided by the mutual conductance (be careful with the "units"—express the milliamps in amps).

Now there is a little "spot of bother" about these curves if you are *experimenting* in wireless. They are really *static characteristics, i.e.* they assume constant voltages applied to the valve: but voltages are always changing when a signal is coming in. What we really want are *dynamic characteristics* if we desire to estimate maximum

outputs, etc. But we can manage by curves with anode volts along the horizontal and plate current on the vertical, which show the plate current at various plate and grid volts. A full explanation is beyond this book, but to indicate the idea we have roughly drawn (Fig. 140) a few

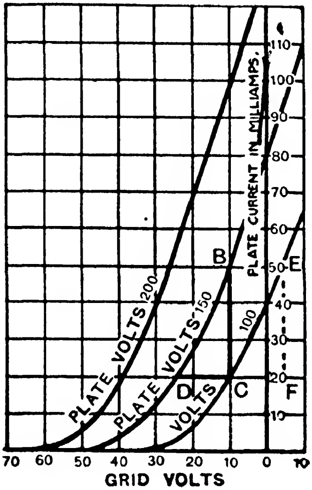


Fig. 139.

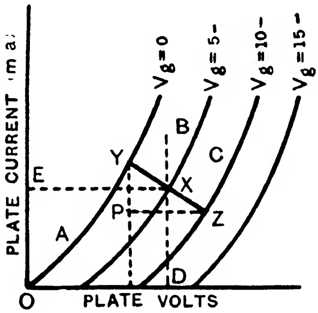
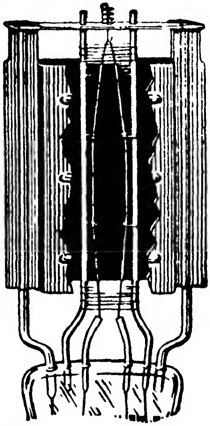


Fig. 140.

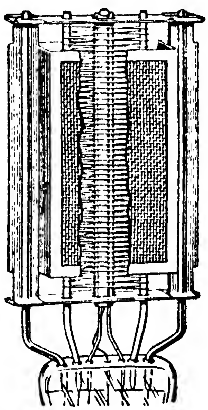
such curves for an output valve; A is with half volts on the grid, B with normal grid volts, and C with twice the normal grid volts. D is the normal plate volts, and E the normal plate current. Now draw a line through X, viz. YXZ, so that YX = XZ, and complete the right-angled triangle YPZ. Then it can be shown that (YP × PZ) ÷ 8 gives the " power " delivered to the outside circuit (*e.g.* the loud speaker), YP is in milliamperes and PZ in volts, therefore the formula gives the power in milliwatts. And the more power delivered the bigger the volume of sound. YXZ is really a dynamic characteristic. For practical reasons (the question of distortion) YX : XZ is usually taken 11 : 9 in practice. PZ/PY = equivalent resistance of loud speaker.

8. Types of Valves—Triodes, Screened Grids, Pentodes, and Mains.

In selecting a valve, three facts should be borne in mind viz. (1) only those made by a firm of repute should be considered, (2) the valve chosen should be one designed for the work it has to do—high frequency amplification or "detection" or low frequency amplification or the last output stage, and (3) the valve should have characteristics making it suitable for "team" working with the other components in the circuit. This last point will be dealt with in the chapter on receivers.



(*a*) Plate and Grid cut away.



(*b*) Cathode in Cossor Mains Valve.

Fig. 141.

Messrs. A. C. Cossor manufacture an excellent series of valves. We have carried out exhaustive tests on **Cossor** valves, have found them always reliable, and can recommend them. The construction of a typical triode is shown in Fig. 141. The filaments are secured to mica bridges, being held firmly in position by small spiral springs and also by four insulated hooks welded to the grid supports. Altogether the filament suspension is a seven-point one which prevents filament vibration and the microphonic

noise frequently caused by such vibration. The suspension is clearly seen in Fig. 141 (*a*) where the plate and grid inside have been cut away to show it. Apart from giving strength, the mica bridge construction ensures that the distances between plate, grid, and filament are kept fixed, thus giving constancy to the performance of the valve.

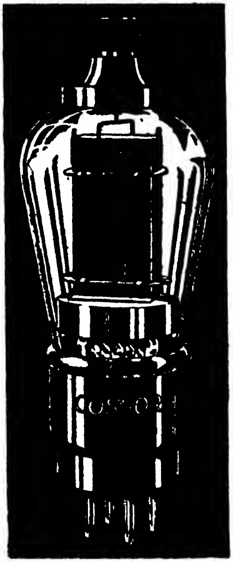
The Cossor 220SG is a two-volt screened grid valve taking a filament current of ·2 ampere: it follows the general construction but is fitted with four mica bridges. It is a medium impedance valve (200,000 ohms) with an amplification factor of no less than 320. The inter-electrode capacity is very low—only about ·0008 micro-microfarad. It can be had with either a plain bulb or a metallised one: the latter, as will be seen later, results in improved screening with the consequent elimination of "howl" and "hum" and improved selectivity.

The 220VSG is a variable mu screened grid. With ordinary grid bias it works just like the ordinary screened grid. As the negative grid bias is increased the magnification diminishes so that the magnification can be varied by varying the grid bias: further, the curve for the valve shows practically no "anode bend point" or knee so that the bias can be increased without the valve beginning to rectify.

The Cossor 210HF can be used either as a triode high frequency amplifier or as a detector: it has an impedance of 16,000 ohms and an amplification factor of 24, the filament current being ·1 ampere. The corresponding 210LF is primarily intended for the first stage of low frequency amplification: its impedance is 10,000 ohms and its amplification factor 14. The 220P is a power valve suitable for the last stage of many three-valve circuits on the market to-day. The Cossor 230PT is a pentode valve of the highest grade. The Cossor range includes in all over 60 types of 2, 4, and 6 volt battery valves and mains valves, all having more or less the same general construction but differing in details.

Another really excellent series of valves, which we have also thoroughly tested and can recommend, is the **Mullard.**

The filament is particularly long and thick which results in a good flow of electrons even at comparatively low temperatures: at the same time it is very strong and has a low current consumption.



Cossor Screened Grid.

Fig. 142.

Cossor Pentode.

Fig. 143.

The Mullard valves comprise a complete range of 2, 4 and 6 volt valves together with a complete series of mains valves. Special triodes are available for high frequency and low frequency amplification and for detection, whilst there are useful groups of both screened-grid and pentode valves. In the screened-grid class types can be had with amplification factors up to 350. The special detector valves are worthy of note, such as the PM2DX, the PM4DX, and the PM6D. The outstanding Mullard pentode is the PM24A, which is a very useful power pentode: it is a four-volt valve which takes a filament current of ·275 ampere,

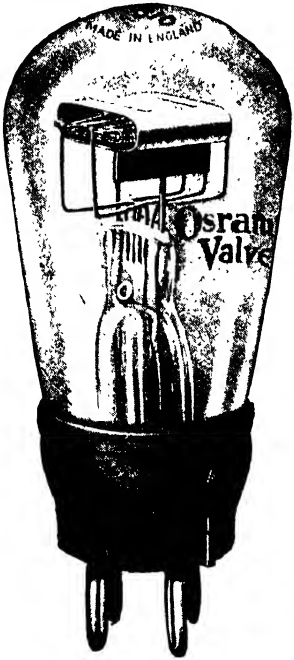
its impedance being 53,000 ohms, and its amplification factor 83. A typical power valve is the PM256A, which can be used with either accumulator or mains supply: it has a comparatively large grid swing, yet steep slope, and low impedance (1400), so that it can handle great power without distortion.

The Mullard valves also include a full range of indirectly heated cathode AC mains valves: thus there is the 354V with an impedance of 14,000 and a magnification of 35, which works well either as a high frequency amplifier or detector, the power valve 154V with 7500 ohms impedance and a magnification of 15, and a super-power of 2800 ohms impedance and amplification factor 10. Valves can be had with plain or metallised bulbs.

A third series of high grade valves made by the well-known General Electric Co. is the **Osram**, which can be depended upon for consistency and reliability and are of a robust character. The special "Wembly filament" employed has wonderful electron emission properties: it is longer than is the case in many valves and is anchored at different points, thus ensuring firm fixture and eliminating microphonic noise. Two, four, and six volt battery types and mains types are available. The screened-grid S22 is suitable for battery sets requiring high magnification from one stage: its impedance is 200,000 ohms, its amplification factor 350, and its filament current ·2 ampere. The HL2 is an excellent detector valve with an impedance of 18,000 ohms, and a filament current consumption of ·1 ampere. The P2 is a last stage super-power valve with an impedance of 2150 ohms, an amplification factor of 7·5, and filament current of ·2 ampere. The PT2 deserves notice as an excellent power output pentode which is suitable for use after a stage of low frequency amplification. Special mains valves either directly or indirectly heated are available. The whole Osram range contains over 50 types.

Other groups of outstanding good valves are the **Mazda**, the **Six-Sixty**, the **Triotron** and the **Philco**. Some special features of the last named will be mentioned later. Valves of recent introduction are dealt with in Art. 9.

For high frequency amplification the screened-grid valve has been applied to most modern receivers, for its amplification is wonderfully high and its inter-electrode capacity very low. For the output stage—the last valve—the power and super-power triodes are still largely employed, but there are circuits for which the pentode is undoubtedly



Osram Triode.
Fig. 144.

Osram Mains Valve.
Fig. 145.

superior. The essential difference—apart from the extra grid—depends on the fact that the impedance of the pentode is large compared with that of the average power valve—of the order 20,000 to 60,000 ohms as against the order 3000 to 5000 ohms. Thus if a pentode be put in the last stage in place of a power *without any alteration in*

the output circuit, the result may be disappointing—the bass may be very deficient and the treble predominate rather unpleasantly. By using a suitable loud speaker and an output transformer or choke and "corrector circuit," as explained in Chapter XI., the full advantages of the pentode can, however, be brought out, and increased amplification and greater signal strength obtained.

Note that a triode valve has four legs or pins in its base, two being joined to the ends of the filament, one to the plate, and one to the grid. In the screened grid the plate is joined to a terminal at the top of the valve and the extra screening grid is joined to the base pin to which the plate is joined in the case of the triode. In the pentode the screening grid is often joined to a *side* terminal. Indirectly-heated mains valves have *five* base pins, two joined to the heater, one to the plate, one to the grid, and a central pin joined to the cathode. Sometimes pentodes have five base pins, *i.e.* a central fifth pin instead of the side terminal.

9. Newer Valves.

Since the beginning of 1933 many special valves have been introduced which are rapidly finding a place in modern receiver design. These new valves are mostly modifications, refinements, and extensions of the standard types already dealt with, and aim at securing greater efficiency and general excellence in wireless reception: the fundamental principles of valve actions already dealt with remain, of course, unchanged. It is impossible to fully *understand* "the why and the wherefore" of these valve modifications until you have studied the principles involved in the design of receiving circuits and receivers given in succeeding chapters, but as you will repeatedly come across them in your reading, reference to the new comers will be an advantage at this stage.

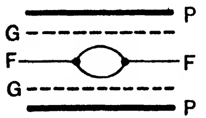


Fig. 145 (*a*)

Perhaps the new valve which came most prominently

into use on its advent in the early part of 1933 is that known as the **Class B output valve**, which was already popular in America and which is employed as the last valve in a receiver using a new system of low frequency amplification (Art. 3), called *Class B amplification*. This system is explained in Chapter XI., and the full action and advantages of the Class B valve will then be realised. Briefly we may say here that it has been found that *two* valves instead of one in the output stage of a receiver,—say two pentodes, —suitably coupled and arranged, can be made to give a much greater output signal strength without distortion, and with a saving in the consumption from the high tension battery. Now the Class B valve owes its origin and development mainly to this fact, and is really two triode valves combined in one glass envelope; it has two plates, two grids, and two filaments. Fig. 145 (*a*) shows diagrammatically the principle of the arrangement of the electrodes where P.P represent plates, G.G represent grids, and F.F filaments, whilst Fig. 145 (*b*) shows a complete Cossor valve.

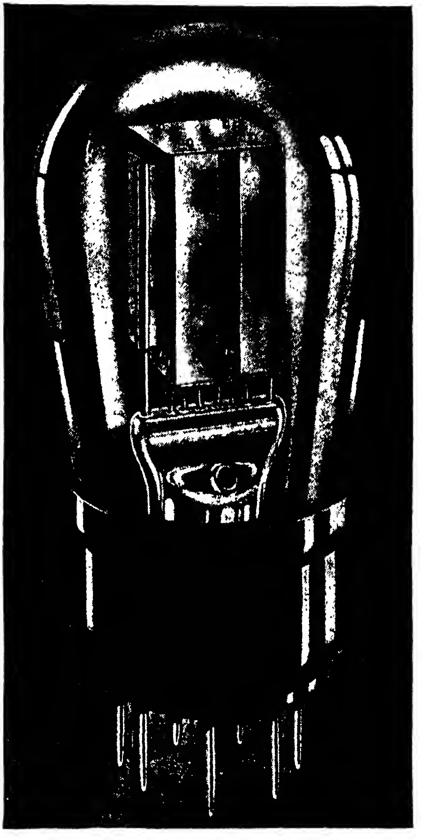


Fig. 145 (*b*). Cossor Class B Output.

There are seven pins or legs in the valve base, and new valve holders with seven sockets (instead of the usual four or five) are available to fit them. Fig. 145 (*c*) shows the socket arrangements of the new valve holder. It will be noticed, however, that there are really only two filament pins—this is because the filament connections inside the valve are common to both filaments.

Some circuit arrangements for a receiver using Class B amplification and the Class B output valve are given in Chapter XI., and it will be seen there that the special merit of the Class B valve and its circuit arrangement is that large power-output can be obtained from a battery receiver—equal to that of an average mains receiver—without distortion, and with quite a modest drain on the high tension battery. Thus the Cossor 240 B type can give a volume-output about 12 times that of an ordinary standard output power valve, yet the current drawn from the high tension battery is less than that of an ordinary output valve. The ordinary valve draws high tension current quite irrespective of the work it is doing, the same, for example, during a programme interval as during a military band item, but the Class B does not: during a programme interval the high tension consumption falls to 2 or 3 milliamperes.

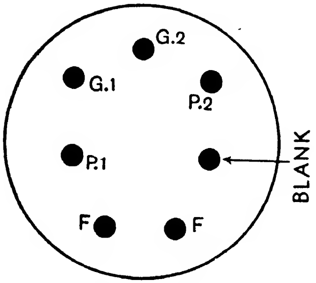


Fig. 145 (*c*).

The filament current (from the accumulator) of the first Class B valves was ·4 ampere at 2 volts and the output power about 2 watts (compare this with 200 *milliwatts*, the output of many battery sets with ordinary output valves). Valves with less filament consumption can now be obtained —about ·2 ampere. The Class B valve and its amplification method seem to have a promising future. And it can readily be applied to any existing battery receiver: this will be seen in Chapter XI.

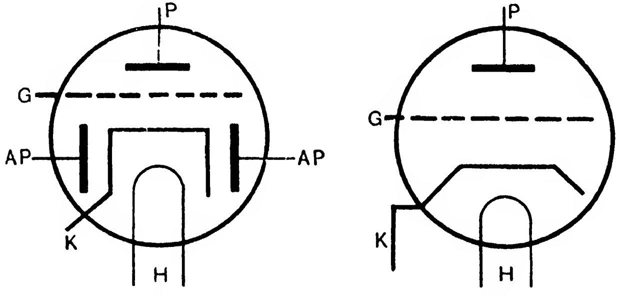
Another important valve is the **double-diode-triode valve.** The diode valve, as we have seen, consists of a filament and a plate (Fig. 124). It is a perfect detector or rectifier—current, you will remember, flows when the plate is positive but not when the plate is negative, so that an alternating current is efficiently changed into a one-direction current—but it does not amplify as a triode valve does: hence if a diode detector is used in a circuit an additional low frequency amplifying triode valve is necessary to obtain signals of the same strength as when a less efficient triode detector is used. To utilise the advantages of efficient diode rectification and triode amplification a new valve has been designed, in which the two—diode and triode—are combined in a single envelope as one valve.

But another (though related) factor, mainly associated with powerful mains receivers, brought about the rapid development of the new valve. The " fading " of signals from distant stations and the " blasting " of strong signals from local stations were defects which demanded attention. Some method of increasing the amplification or magnification when weak signals arrived and decreasing it on very strong signals was required. And to be a success this regulation should be automatic, *i.e.* it should be done, as required, by the receiver itself, not by the listener constantly turning a knob. " Automatic volume control " (A.V.C.) was wanted.

Now the variable-mu screened grid valve which is used in the high frequency stage as a high frequency amplifier (*i.e.* before rectification or detection by the detector valve), simplified matters, for the amplification or magnification which it produces can be altered by even slight alterations in the biasing voltage given to the grid. If the negative bias is reduced the valve amplifies more (you are using a steeper part of the curve), and if it be increased the valve magnifies less (you are using a less steep part). This can readily be seen if a curve for the valve be examined.

Now imagine that somehow or other the output of a detector valve can be connected to the grid circuit of the high frequency amplifying variable-mu valve in front of

it in such a way that it regulates the *negative* bias on the grid of this high frequency valve. If the rectified output voltage of the detector becomes low (weak signal) the grid bias on the high frequency valve will be reduced and its amplification will increase, and similarly if the rectified voltage tends to become excessive the grid bias is increased and the amplification will be reduced. This is the elementary principle of automatic volume control. Further, it was soon found that with powerful sets a *diode* was the only detector which could handle the voltage properly to provide the necessary varying bias on the preceding variable-mu to secure this necessary A.V.C.



Double-Diode-Triode. Ordinary Mains Triode.

Fig. 145 (*d*).

All the points mentioned above, then, led to the advent of the *double-diode-triode valve,* which consists of a cathode (indirectly heated), a grid, and a main plate or anode, and in addition two smaller plates known as auxiliary plates. The principle is shown in Fig. 145 (*d*), where a similar figure for the ordinary mains triode is given for comparison. The main plate, grid, and cathode (with heater) constitute the usual mains triode whilst the two auxiliary plates and the cathode are two diodes. The valve is thus two diodes and a triode in one. A screen is inserted between the auxiliary plates and the other elements to prevent interaction. This double-diode-triode, then, serves as a detector (the diode portion) and as a low frequency amplifying valve

(the triode portion), the diode part being also used in conjunction with the preceding variable-mu for A.V.C.

A modification of the above is the **double-diode-pentode valve** of Messrs. Cossor: it is similar in general principle,

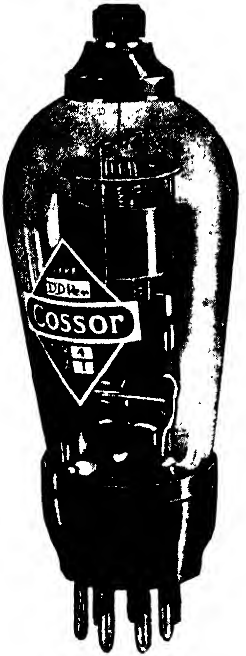


Fig. 145 (*e*). Cossor Double-Diode-Pentode.

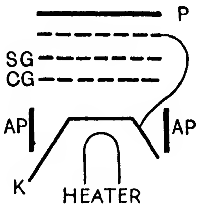


Fig. 145 (*f*).

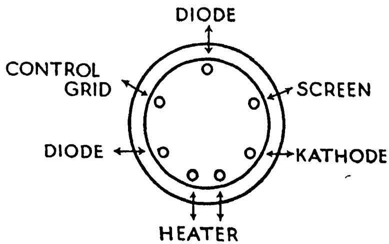


Fig. 145 (*g*).

but it contains the extra grids just as a pentode does. The Cossor DD/PEN is this type of valve and is shown in Fig. 145 (*e*): it consists of the two diodes as above, but instead of a triode portion it embraces a special *variable-mu pentode* portion. The arrangement of its elements is diagrammatically shown in Fig. 145 (*f*), and the manner in which its seven base pins fit into a seven-pin holder is shown in Fig. 145 (*g*): the top terminal of the valve

(Fig. 145 (*e*)) is, as usual, connected to the main plate, *i.e.* the plate of the pentode portion. The two diodes provide rectification and A.V.C., and the pentode provides low frequency amplification: in this case A.V.C. can be used, not only on the preceding high frequency variable-mu valve, but also on the variable-mu pentode portion of the valve, *i.e.* on both high frequency and low frequency parts of the circuit. This ensures an almost perfect automatic volume control of signals.

As a further help towards A.V.C., what is known as the **short base variable-mu valve** has been introduced for the high frequency stage. This is simply a variable-mu in which a *very small* change in the grid biasing voltage makes a *big* change in amplification: thus A.V.C. is rendered possible with comparatively simple receivers.

Yet another valve, the **high frequency pentode valve,** is now largely employed. We have said (Art. 2) that if large voltage changes were applied to the controlling grid of a screened-grid valve the potential of the plate might in its "swings" get down below the potential of the screening grid and the latter might then begin to rob the plate of its electrons: it was also explained that to avoid this in low frequency amplification, where larger voltages are handled, the pentode valve was introduced with another grid between the screening grid and the plate, this added grid being joined to the filament.

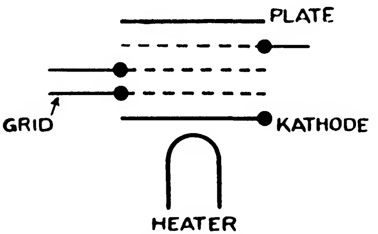


Fig. 145 (*h*).

Experience has shown, however, that even when the screened grid is used for its normal purpose of high frequency amplification, cases arise where the screening grid robs the plate with the result that the valve tends to fall into oscillation and does not function properly. This has led to

the introduction of the new *high frequency pentode valve*, which is made in both ordinary screened grid and variable-mu forms. The Cossor MVS/PEN is this type of valve, *i.e.* it is a *variable-mu high frequency screened pentode.* In one type the extra pentode (or suppressor) grid is joined to the cathode, in which case the valve has a five-pin base: in another type the suppressor grid is brought to a base pin instead of to the cathode, and a seven-pin base is used. Fig. 145 (*h*) shows the arrangement of the elements in this latter case and Fig. 145 (*k*) the seven-pin holder; the plate is, of course, joined to a top terminal. This high frequency amplifying valve will, we think, become the H.F. amplifying valve of the future.

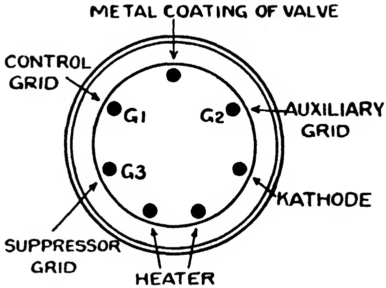


Fig. 145 (*k*).

Fig. 145 (*l*).

The modern **Catkin valve** is an A.C. mains valve of the four volt type. It is constructed almost entirely of metal (hence it is referred to as the *all-metal valve*) which results in increased strength, smaller size, and the absence of "microphonic" defects when working.

The containing envelope is of copper instead of glass, and this forms the anode or plate of the valve. This is screened by a metal tube extending the whole length of the valve, and holes are provided in this to permit of the dissipation of heat. The various electrodes inside are firmly anchored at the correct distances by spacing pieces of mica. The only glass used

in the valve is the small amount employed as insulation where the wires come out at the valve base. The valve is not rigidly fixed to the cap as in the case of the glass valve: it is held in a rubber ring, the leads passing into an insulating cap carrying the valve pins. The valve is smaller than the usual type and is thus ideal for receivers which must be kept compact. For " radio in the car" sets they seem very suitable.

Fig. 145 (*m*). Westectors—the new *half wave* and *full wave* " cold " rectifiers.

The Osram Catkin valve is shown in Fig. 145 (*l*): it employs a standard base and so can be fitted into any suitable mains receiver. Screened grid, variable-mu screened grid, triode, and pentode types are obtainable.

Incidentally, *transmitting* valves in metal containers have been used for some time. The containers are the anodes which, in the case of transmitting valves, are water cooled, the whole being referred to as " cooled anode transmitters " or C.A.T. This led to the name " catkin " for the new valve.

The new **cold valve**, as the Press persists in calling it, has been placed on the market as a detector or rectifier under the name **Westector** by the Westinghouse Brake and Saxby Signal Co. Ltd., and two forms of it are shown in Fig. 145 (*m*). The general idea of this is rather similar to

that explained in the case of the crystal detector. Imagine a sheet of copper with one face oxidised, and that a current is to be passed *through* the sheet. Now at the junction of the copper and the film of copper oxide there is a certain electronic action: we may say, in fact, that the "resistance" from copper to oxide is considerably greater than the "resistance" from oxide to copper. Thus, just as in the case of a crystal, if a high frequency alternating current be applied, the device will refuse the current in one direction and pass the other. We have therefore a rectifier or detector: this is the principle of the *Westector* "valve."

The "Westector" is small, compact and robust, and it requires no "heater" or "anode supply": it can be used for ordinary circuits or for super-heterodynes.

A valve which has been developed on the Continent and in America is the **hexode valve.** It is a mains valve fitted with a cathode (indirectly heated), four grids, and a plate arranged as indicated in Fig. 145 (*n*). This valve is intended for use in super-heterodyne receivers and it combines the functions of a variable-mu screened grid detector and what is known as the "oscillator valve" in such receivers. It is of special value in superhets employing automatic volume control. Super-heterodyne receivers are dealt with in Chapter XII.

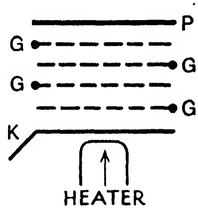


Fig. 145 (*n*).

The Philco **pentagrid valve** is a very efficient valve for superhet use. It is similar in principle to the hexode but contains *five* concentric grids between the cathode and the anode, and, so far as its work is concerned, is really three valves—modulator, oscillator, and amplifier—enclosed in one envelope. In superhets using one valve for different purposes it has sometimes been difficult to prevent interaction between the parts, but this is efficiently eliminated in the Philco pentagrid, the middle grid so functioning that it acts as a perfect screen between oscillator and amplifier portions so that oscillating energy is prevented

from reaching the aerial circuit to cause radiation and interference. Other makes of pentagrids are on the market.

Valves for use either on D.C. or A.C. supplies are now on the market. On A.C. mains the rectifier changes the supply to direct current: on D.C., it acts as a resistance.

There is just another point which might be mentioned before leaving this subject of valves, although a full explanation and proof is beyond the scope of this book. It has been shown (page 162) that for amplification a valve must be so arranged that the steep part of the curve is used. Fig. 130 indicates this, but it will be noted that in this figure P shows the *potential* changes on the grid, and Q the resulting *current* changes in the plate circuit, and to get a proper idea of the actual "magnifying" done by the valve the current changes Q should be converted into the corresponding potential changes, and *the potential changes on the grid compared with the potential changes they cause on the plate* (we could insert a known resistance in the plate circuit and obtain the changes in potential across this caused by the Q current changes).

And now for the case in practice. If R be the resistance in the plate circuit of our valve, R_a the differential resistance (or impedance) of the valve, and μ the amplification factor, it can be shown that:—

$$\text{Change in plate potential} = \mu\frac{R}{R + R_a} \times \text{Change in grid potential},$$

and if R_a is small compared with R so that we can neglect it, this becomes:—

$$\text{Change in plate potential} = \mu \times \text{Change in grid potential}.$$

Thus, if we have a valve arranged for amplification (*i.e.* using the steep curve) and worked under these conditions (R_a negligible compared with R), and if the manufacturer gives its amplification factor as 50, it means that a change of 1 volt *potential* applied to the grid produces a change of 50 volts in the plate *potential.*

CHAPTER IX.

CRYSTAL RECEIVERS.

1. A Glance at Two Old Friends of the Early Days.

Crystal receivers are now rarely used, although a few people still favour them if they are near a local station, or if the long wave "National" comes within the crystal range: in any case they form a convenient "stand-by" even for the multi-valve owner. The initial cost is low, the working expenses are nil, and the headphone reception is pure and pleasing. We will very briefly indicate one or two crystal circuits to illustrate the general principles.

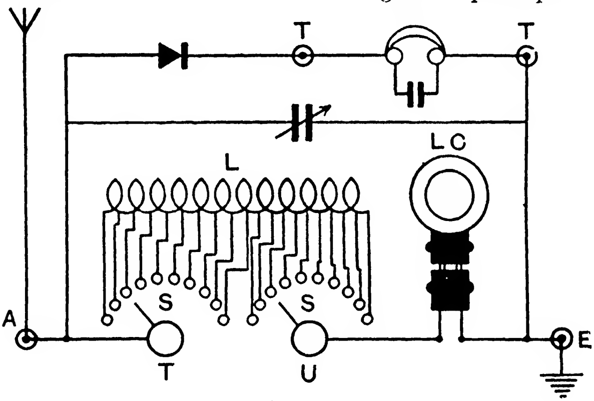


Fig. 146.

It will be interesting to look first at two old friends of the early wireless days. They will probably bring back pleasant recollections to many—the pioneer days—the days when we enthusiastically built crystal sets to go into our waistcoat pockets, and others almost requiring a hand-cart to move them about. But they illustrate principles still in use to-day.

Fig. 146 shows the connections of the ***tapped inductance crystal receiver.*** The inductance L was made of 100 turns of 24 gauge insulated (double cotton) copper wire wound on a cardboard tube 3 inches in diameter and 6 inches long, and, from different points of the coil tappings were taken to the two sets of studs shown. Between one stud and the next in the U set of studs one turn was connected, whilst between each pair in the T set of studs ten turns of wire were connected. Connection to different parts of the coil was made by means of the rotating switch arms S, S.

A small fixed condenser of about ·002 mfd. capacity joined across the telephone terminals sometimes improved the reception, for it formed a by-pass for any *high frequency* pulsations of current: it also helped the audio frequency pulsations to pass through the telephones. The *loading coil* LC was used when receiving the long waves: it was a plug-in coil, No. 150 or 200. The coil was removed and the holder short circuited when receiving on the ordinary broadcast band.

In tuning, the switch at T was placed on the first or second tens stud and the switch at U slowly moved over the whole of the units studs. If no signals were heard T was placed on the next tens stud and U again slowly moved over the whole of the units studs. This was repeated until signals of good strength were heard.

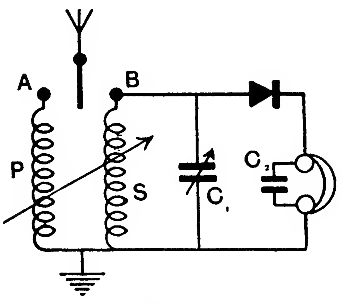


Fig. 147.

Still finer tuning is obtained if a variable condenser of about ·0003 or ·0005 microfarad capacity be joined between the aerial and earth terminals as shown. In this case tuning is first carried out as above, and then the condenser is varied.

Sometimes a variable condenser was put in series with the coil. Whether a series or a parallel arrangement is

better in any particular case depends upon aerial conditions, etc., and must be settled by trying both. In a general way a parallel arrangement is better—and certainly for longer waves: the series often cuts down signal strength too much.

Fig. 147 shows the principle of one form of *loose coupled crystal receiver*. The two coils P and S were mounted in a two-coil holder, P being fixed and S movable, so that its distance from P could be varied. The variable condenser C_1 had a capacity of ·0005 microfarad. C_2 was the usual fixed condenser of about ·001 or ·002 microfarad.

With the switch on stud A the circuit is a coupled one. In this case, for the broadcast band of waves, P may be a No. 35 or 50 coil and S a 75: for the long waves P may be a No. 150 or 200 and S a No. 200 or 250 accordingly. Tuning was done by varying the distance between P and S and adjusting the condenser C_1.

This arrangement is known as *loose coupled semi-aperiodic aerial tuning*: in it we have a fixed untuned coil in the aerial circuit, loose coupled to a tuned coil in the crystal circuit, its tuning being done by C_1.

If the switch be tuned to the stud B the coil P is cut out and we get a *fixed coil circuit*. In this case for ordinary stations S may be a No. 35 or 50 coil, and for the long waves a No. 150 or 200 coil.

2. Fitting in with Modern Broadcasting Conditions.

With the introduction of the Regional scheme in Broadcasting the matter of "selectivity" in a crystal set became much more vital than it was in the early days. Thus listeners within a distance of 40 miles or so of the two Brookmans Park transmitters (working at great power on waves of 261 and 342 metres) found it difficult to separate the Regional from the National with the older type of crystal receiver.

A crystal, of course, always absorbs energy from the circuit and must cause damping: this damping lowers the selectivity. Moreover, attempts to improve selectivity lessen

the volume, and as the crystal does not amplify as a valve does but merely works with the small input from the aerial, cutting volume to secure selectivity cannot be carried very far.

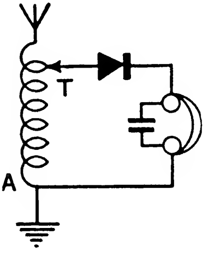


Fig. 148.

Now it can be shown that if this damping can be varied and made of the same order as that due to other resistances in the circuit the signal strength will be increased. Fig. 148 shows a circuit with this object in view: it is modified from that of Fig. 146 in the sense that the crystal is tapped across part of the inductance only, and by varying this tapping it is clear that the damping in this circuit can be varied until the best condition is found.

If this tapping point T be quite close to A the portion of the voltage across the inductance which is available for the crystal and telephones is quite small, with the result that the signals are weak. As the tapping point is raised the signals become stronger, until a point is reached where the signals are a maximum. If the tapping point be still further raised the signal strength falls off owing to the damping. Fig. 149 gives the general shape of the curve showing the relation between the tapping point and the signal strength. Tuning consists in finding the tapping point which gives the peak of the curve. This tapping also improves selectivity.

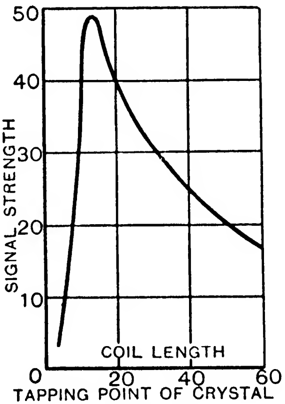


Fig. 149.

An *auto-coupled aerial circuit*, as it is called, *i.e.* an aerial tapped across part of the inductance on a principle similar to Fig. 146, may be combined with a crystal tapping as

indicated in Fig. 150. By this method good selectivity and sensitivity are obtained with good volume.

Again, in most early crystal receivers the crystal circuit was fixed direct across the aerial, thus forming part of the one and only tuned circuit to fight against any interference from unwanted stations. Modern crystal circuits often utilise the property of induction between a primary coil in the aerial circuit and a secondary coil in the crystal and telephone circuit: this general idea was used in some early forms, as is shown in Fig. 147. The aerial circuit is, however, tuned by tappings or a condenser, or both, to the arriving waves, and the secondary or crystal circuit is tuned to the primary circuit. In such a case the crystal

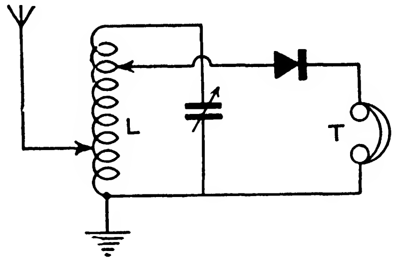


Fig. 150.

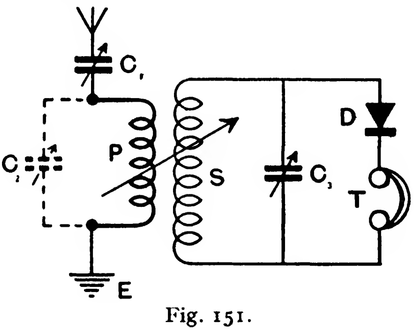


Fig. 151.

circuit, being separate from the aerial circuit, has not got the damping of this latter circuit connected with it, and in consequence its tuning is sharper, and interference is reduced. Fig. 151 shows diagrammatically the arrangement: the tuning condenser in the aerial circuit may be

either in series or in parallel. Further, P and S may be fixed, or the distance apart, *i.e.* the coupling, may be variable: this latter is the true "loose coupled" form. The secondary circuit is tuned by C_1.

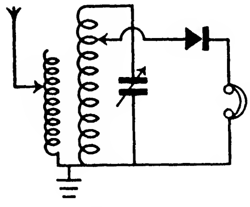


Fig. 152.

A combination of the inductive principle and the tapping principle can be adopted with excellent results. Thus the aerial may be tapped to the primary, and the crystal circuit tapped to the secondary, the secondary being tuned also by the variable condenser in the usual way. This is indicated in Fig. 152.

3. Two Modern Crystal Circuits.

We can now apply some of the preceding principles to the construction of a crystal receiver suited to modern conditions.

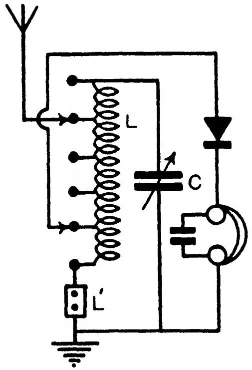


Fig. 153.

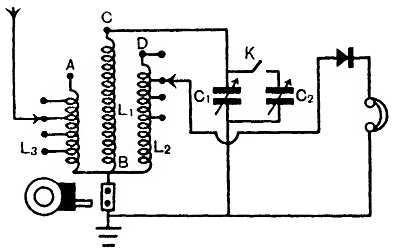


Fig. 154.

Fig. 153 gives a circuit which is a direct application of the tapped aerial and tapped crystal circuit. The aerial inductance L consists of 50 turns of D.C.C. wire of 24 gauge wound on a tube of cardboard or other suitable

material 3 inches in diameter, tappings being taken to terminals at every 10 turns. L_1 is a coil holder into which a loading coil (say a No. 150) may be plugged for the long waves and which must be short circuited for the broadcast band. The variable tuning condenser C is of ·0005 microfarad capacity. The aerial and crystal circuits may be joined to any of the five terminals provided on L. The best positions are found by trial, final "tuning" being done by C.

Fig. 154 gives another circuit which utilises the tapping principle of the aerial circuit and the crystal circuit, and also the coupling principle between a primary in the aerial circuit and a secondary circuit. The coil L_2 consists of 35 turns of silk-covered copper wire of about 36 gauge wound on a tube about $2\frac{1}{2}$ inches diameter, with tappings at the 20th, 25th, 30th, and, of course, 35th turns. The coil L_1 consists of 60 turns wound on the same tube—a thicker wire should be used for this. Both L_1 and L_2 start from the same terminal B fixed to the tube, and although shown separate in the figure, they are wound on together as far as the L_2 coil extends. The coil L_3 which forms the primary in the aerial circuit consists of 25 turns of the 35 gauge wire wound *over* the other coils (although shown at the side in the figure), this primary also starting from terminal B, and being tapped at every 5 turns. The primary winding is kept separated from the other coils by eight small pieces of vulcanite placed against the other coils at equal distances round the circumference of the tube, the primary being wound tightly over these distance pieces, its end being finally joined to terminal A.

The condensers C_1 and C_2 are of maximum capacity ·0003 microfarad.

In tuning in to your local station open the switch K, thus cutting out C_2, and short circuit the loading coil holder. Then get the best positions for the aerial and crystal taps making the final adjustment on C_1. Leave C_1 and the tappings. Insert the loading coil and close K thus bringing in both condensers (in parallel), and adjust C_2 for best

signals. You can now receive either your local station or the " National " merely by opening or closing the key K and short circuiting or inserting the loading coil.

The method of making, fixing to the crystal set, and using a " wave trap " to further " cut out " any persistent interfering station is explained in the next chapter.

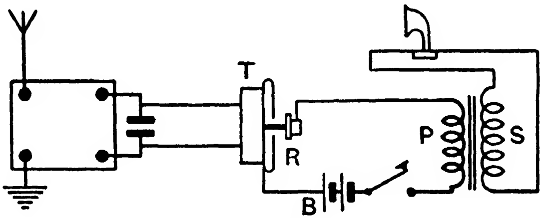


Fig. 155.

4. Increasing the Signal Strength of a Crystal Receiver.

Every crystal user, in time, wishes to increase the strength of his signals, *i.e.* to get a louder sound in his telephones, and the best method is to use a *low frequency amplifying valve*, which will take the rectified varying currents from the crystal and magnify them before passing them on to the telephones. This method will be understood after valve circuits has been dealt with.

Many attempts have been made to increase the signal strength of crystal receivers without the use of valves, and some have met with a certain amount of success, but the valve is undoubtedly the best. One method is indicated in Fig. 155. The telephone terminals of the crystal set are joined to a single telephone ear-piece T. Attached to the diaphragm of the ear-piece by means of a light rod is one electrode of a small relay R. Between the two electrodes of the relay are carbon granules. The circuit of the relay is completed through a battery B of 4 dry cells and the primary coil P of a transformer, the secondary coil S of which is joined to the telephones or loud speaker.

Clearly the vibration of the diaphragm of the telephone ear-piece, due to the signals received, is transferred to the

relay, producing compressions and decompressions of the carbon granules, and thus varying the resistance in the battery circuit. This results in corresponding variations in the current from the battery, which variations are magnified by the transformer, and the loud speaker responds, giving out signals the same as are received by the telephone ear-piece, but magnified.

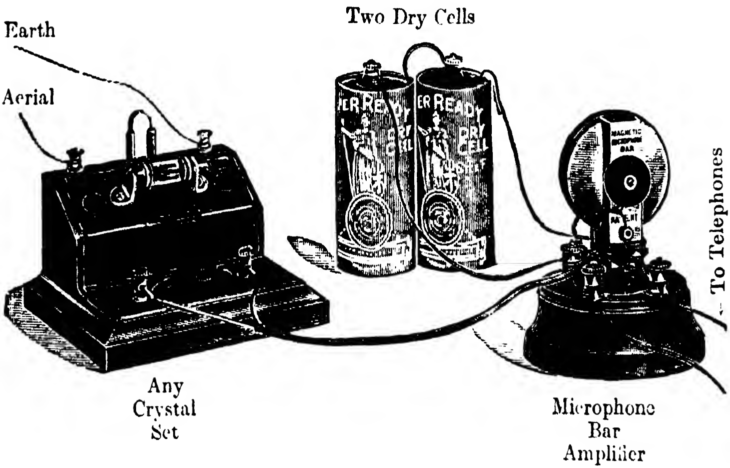


Fig. 155 (*a*).

A somewhat similar device known as the "microphone bar" was also put on the market, and it works pretty much on the same principle. The bar clamps to a telephone ear-piece in the usual telephone circuit of the crystal set, and includes in its circuit a transformer, two dry cells, and the receiving telephones or loud speaker after the manner of Fig. 155. Fig. 155 (*a*) shows the arrangement.

The two methods indicated are, however, mainly of (shall we say) "historical" interest: they were steps in the ladder of wireless experiment—and progress.

CHAPTER X.

SINGLE VALVE RECEIVERS.

1. Reaction or Back Coupling.

Almost every crystal user turns his attention sooner or later to valves, and naturally the one valve receiver first attracts his attention. And particularly is this so if he is of an experimental turn of mind, for the one-valver opens up a wide range of simple experiments for those so inclined:

Now before proceeding further look back at Figs. 133 and 135 to get again the general idea of the connections of a valve circuit to the aerial inductance and earth. In Fig. 133 the contact on the potentiometer across the low tension battery was adjusted so that the steady grid potential fell at the bottom knee of the valve curve, and anode bend rectification was used. In Fig. 135 the more usual grid leak rectification was used. In both cases the oscillatory potential differences set up at the aerial inductance by the arriving waves are applied between the grid and filament, and the result is corresponding but *uni-directional* current changes in the plate circuit of the valve which operate the telephones.

The above simple straight circuits are rarely used, however, for in most cases some form of what is called **reaction** or **retro-action** or **back coupling** is employed, thereby (amongst other things) increasing signal strength, whilst special arrangements are introduced to eliminate interference and improve selectivity.

As already indicated, the oscillatory potential differences set up in the aerial are applied between the grid and filament of the valve. Now some of this received energy in the grid circuit is dissipated or wasted in the resistance of the grid circuit and, of course, the amount of energy actually available for the valve to work with is reduced.

Clearly then, if this dissipated energy can be made good by adding energy in some way to the grid circuit from some other source, the voltage variations between the grid and filament will be greater, the corresponding changes in the plate current will be greater, and signal strength will therefore be increased. This is accomplished by the arrangement shown in Fig. 156, and is known as *reaction, retro-action*, or *back-coupling*.

In the figure L_2 is an inductance, called the **reaction coil,** in the plate circuit of the valve: it is coupled to the inductance L_1 in the aerial and grid circuit, the distance between the two coils being usually variable: this variable coupling is obtained by mounting L_1 and L_2 in a two-coil holder, the coils being side by side and L_2 movable so that the distance between them (the coupling) is variable. The varying current in the L_2 and plate circuit acts inductively on L_1, thus adding energy to the L_1 and grid circuit, and by suitable arrangement of the value of the reaction coil L_2 and the distance between L_1 and L_2, this energy can be made to help that in the grid circuit, and to compensate for the energy dissipated in this circuit: in other words, energy is being fed back from the plate circuit to the grid circuit, to make up the loss there. The result is greater signal strength.

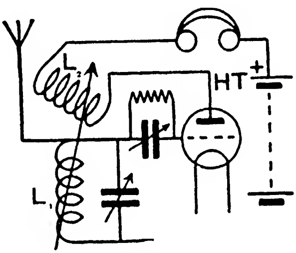


Fig. 156.

The connections of the reaction coil must, of course, be such that the energy fed back assists that already in the grid circuit—the two must, as it were, be in step. If signal strength be weakened when the reaction coil is brought nearer the other coil it is a sign that it is connected the wrong way round, and the connections must be reversed.

It looks at first as if signal strength could be increased in this way indefinitely, but there is a limit. If more than a certain amount of energy be fed back into the aerial and

grid circuit the set breaks into self-oscillation and begins to radiate. Music and speech become distorted, howls and squeaks result from the "heterodyning" (page 131) effect, and you join the ranks of the "oscillating fiend"—that unmitigated nuisance to all listeners in the vicinity.

The object to be aimed at in tuning is to get the reaction coil as close to the other as possible without actually falling into self-oscillation, but you should turn it away immediately on the first sign of oscillation. On getting near the oscillation condition there is usually a rustling sound, signals begin to be distorted, and if the tuning condenser be slightly varied, some whistling and howling will occur.

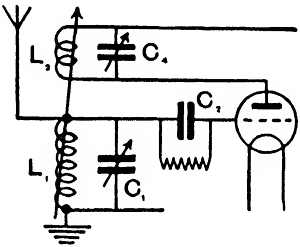


Fig. 157.

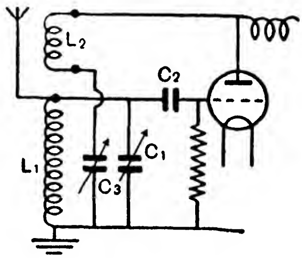


Fig. 158.

Reaction, suitably arranged, increases selectivity as well as signal strength. Since it compensates for the energy dissipated in the resistance of the grid circuit it is, as it were, equivalent to the reduction of the effective resistance: thus we have a "low loss" circuit, and, as already indicated, this results in sharp tuning.

Fig. 157 gives the outline of another reaction method. Here the reaction coil L_2 may be fixed in relation to L_1, and the reaction controlled by the variable condenser C_4. Another plan is to have L_2 movable as in the case first considered: when a signal has been tuned in L_2 is brought nearer to L_1 but not sufficiently near to start the set oscillating, and then C_4 is adjusted until the best signal strength is obtained. Fig. 158 gives yet another method in which L_2 is fixed and the reaction controlled entirely by

the condenser C_3: this latter is really based on a type of circuit known as the *Reinartz circuit*, as will be seen in Art. 3. It appears in most of the circuits in Chapter XI.

All these methods in various forms are used in the wireless receivers of to-day. The " magnetic " reaction of Fig. 156 results in louder signals, but the moving coil takes up much space and the method is not so steady as the others: most constructors therefore favour the " capacity " method of Fig. 158 or some modification of it. The differential type of condenser is frequently used in this capacity reaction, as will be seen presently.

In every receiving set there is, as already indicated, a certain amount of inherent reaction due to capacity and induction between various parts. This stray coupling, if excessive, may cause a set to oscillate without the assistance of a reaction coil, or coil and condenser, and may be a source of trouble. To avoid it as much as possible care must be taken in arranging the various components in a receiver, especially the relative positions of wires, etc., on the input (grid) and output (plate) sides of the valve. Specially arranged circuits have been designed, and specially constructed components have been made, to eliminate this stray coupling or to make it less pronounced (especially in receivers employing several valves), *e.g.* neutrodyne circuits, screened coils (*i.e.* coils surrounded by metal covers), metal screens separating certain parts of the circuit, screened-grid valves, metallised valves (*i.e.* valves coated with a metallic deposit), etc. The reader will come across all these in the modern receivers dealt with later.

2. Two Simple Single Valve Circuits.

We will first give two simple circuits which, although still in use, are not particularly selective for present-day conditions. But they will show general principles better than the more complicated circuits which follow, and that is what we want to do at this stage. For simplicity, too, in the first few diagrams, we assume plug-in coils. Slight modifications may be made for selectivity and sensitivity.

(1) A simple single valve receiving circuit with magnetic reaction is shown in Fig. 159. The aerial inductance L_1 and the reaction coil L_2 are of the plug-in type and are fixed in a two-coil holder (Fig. 61), the coil L_2 being the moving coil. The aerial tuning variable condenser C_1 is of capacity ·0005 microfarad, the fixed grid condenser C_2 is of capacity ·0003 microfarad, while the telephone condenser (if used at all) may be a fixed condenser of ·002 microfarad

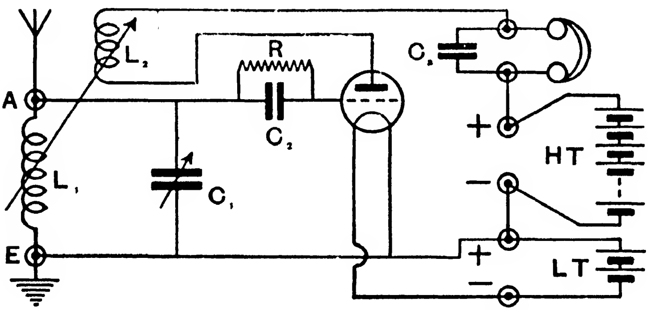


Fig. 159.

capacity. The grid leak R is of 2 megohms resistance. A small condenser of ·0001–·0003 microfarad is often placed in the aerial circuit to improve the selectivity. Note that in this circuit we have joined the high tension negative to the low tension positive (sometimes H.T. — is joined to L.T. —; see later).

The size of the coil L_1 depends on aerial conditions, and should be as small as possible consistent with good signals. If too small, selectivity will be good, but signal strength poor: if too large, both selectivity and signal strength will be poor. For the lower broadcasting band, L_1 may be a No. 35 coil and L_2 a No. 50, while for the higher broadcasting band, L_1 may be a No. 50 and L_2 a No. 75. For the long wave stations, L_1 may be a No. 150 or 200 and L_2 a No. 200 or 250.

Any general purpose or detector valve may be employed, the necessary filament voltage and high tension voltage

depending on the type of valve used (indicated by the valve makers).

The telephones are inserted in the plate circuit as indicated: if the telephone terminals are marked + and − (and all should be), the + terminal should be joined to the positive pole of the battery, so that the current will not go through the telephones in the wrong direction, thus weakening their magnetism.

In tuning in to any particular station, the reaction coil must be well back from the aerial coil, and C_1 must be adjusted until the best signals are obtained. The reaction coil must then be brought gradually up towards L_1 for increased signal strength, C_1 being further slightly adjusted during the process.

(2) Before proceeding far in your valve experiments you will realise the importance of selectivity and the cutting out of unwanted stations. Tapped aerial coils, and coupling between a primary coil in the aerial and a secondary coil in the other circuit, are two methods of improving matters which have been indicated. Fig. 160 shows an application to what is called a *loose coupled circuit with split secondary magnetic reaction.*

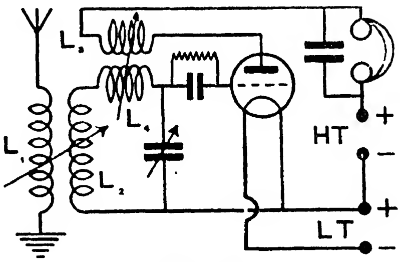


Fig. 160.

In this circuit the inductance in the secondary consists of two coils L_2 and L_4, arranged in the receiving set at right angles to each other so that the coupling between them is a minimum. The aerial coil L_1 is inductively coupled with one of these, L_2, and the reaction coil L_3 is inductively coupled with the other, L_4. For the broadcasting band a No. 50 coil for L_2 and a No. 35 coil for L_4 will be suitable. Two two-coil holders are necessary, one to carry L_1 and L_2 and the other to carry L_3 and L_4. Other values are

similar to those of the preceding circuit. The circuit diagram shown in Fig. 160 is self-explanatory.

In many of the aerial tuning coils on the market the principle of coupling a coil in the aerial with a coil in the grid circuit is employed, as mentioned in Chapter IV.: various tappings are also incorporated, thus bringing in the advantages of " taps." Further, for simplicity, we have used plug-in coils in Figs. 159 and 160, and different coils have therefore to be inserted for the reception of the long and medium waves: by tappings and some switching arrangement modern tuners can be quickly switched over for long or medium waves as required: some reaction device is also frequently incorporated. Thus the modern tuner is a very convenient wireless component, as will be fully realised presently.

3. Two Special Single Valve Circuits.

In the earlier days of broadcasting and the construction of wireless receivers, some special circuits were devised, and the principles of these are often used in some modified form in the wireless receivers of to-day. Amongst such may be mentioned the **Reinartz**, the **Flewelling**, and the **Armstrong** circuits: hence a simple brief account of these will be of interest to you, and you will then recognise the principles in many modern circuits.

(1) Although originally intended for the reception of waves shorter than the broadcasting band, the *Reinartz* circuit can be adapted for the latter. A point in favour of the circuit is that in applying reaction there is very little change in wave length, and therefore the aerial tuning has not to be re-adjusted as the reaction is altered, and moreover, reaction control is smooth and easy. This reaction control is done by a variable condenser: as a matter of fact the capacity control of reaction indicated in Fig. 158 is really a form of Reinartz circuit. The circuit can be very selective.

A form of Reinartz circuit using plug-in coils is shown in Fig. 161. Here L_1 is a plug-in coil which may be a No. 75

and L_2 a tapped plug-in which may be a No. 25: with C_1 of capacity ·0003 microfarad the broadcast band of waves may be dealt with. The coils L_1 and L_2 are in fixed coil holders, the coils being parallel and quite close together. The circuit is manipulated as in the case above, reaction being controlled by C_3 (·0001 or ·0002 microfarad). The choke F may consist of about 270 turns of No. 34 silk-covered wire wound on a vulcanite tube about 1 inch in diameter. It is inserted where indicated in order to choke back any high frequency current from the telephones. For the reception of long waves No. 300 for L_1 and No. 150 for L_2 will be suitable, but in this case a larger choke—a 350 or 400 or larger—must be used. In tuning, C_1 is adjusted for the best signal and then C_3 is used to vary the reaction. The circuit is sensitive and needs that careful handling which comes with practice.

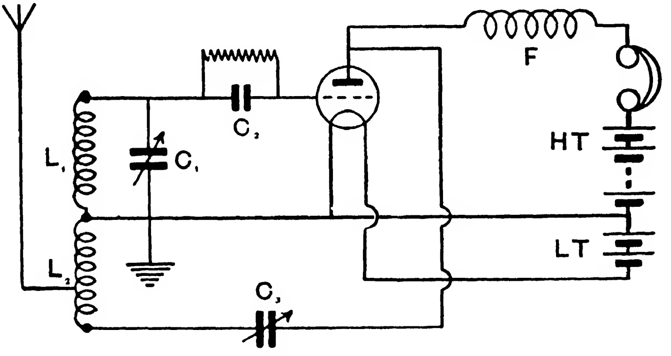


Fig. 161.

(2) Many circuits were designed in the early days to give signals louder than could be obtained as a general rule without the receiver oscillating. The principle of these *super-regenerative circuits*, as they were called, was to introduce intermittent damping into the circuit to prevent oscillations being set up. The intervals between these damping periods are intervals of extreme sensitiveness during which an amount of reaction can be used much

greater than that which can be ordinarily used without the receiver oscillating. Two typical circuits of this type were the *Flewelling* and the *Armstrong*. Incidentally the circuits as originally planned are somewhat critical in their adjustments, and some experience in manipulation must be gained before good results can be obtained.

In many of these super-regenerative circuits the intermittent damping was brought about by opposing at intervals the oscillations applied to the grid. In the *Flewelling circuit*, which we will take as an example, this is done by introducing into the grid circuit capacity, which, by suitable adjustments, can be made to block and free the grid of the valve at a very high rate (15,000 times per second). One form of the circuit is shown in Fig. 162.

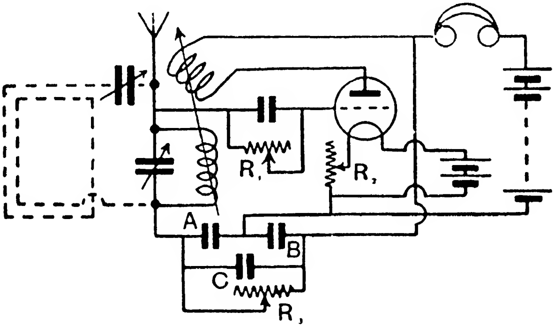


Fig. 162.

In this circuit R_1 is variable and its value should be from ·5 to 4 megohms. A variable resistance R_3 of ·5 to 4 megohms is also used. The three fixed condensers A, B, C are equal and of a value about ·006 microfarad. Other values in the circuit are as previously indicated. The procedure with the circuit is as follows:—

Disconnect the condensers A, B, C, short circuit the wires joined to A, and tune in in the usual way until the best results are obtained. Then replace the condensers, and tune. The resistances R_1 and R_3 are next adjusted until an extremely high pitched whistle is heard. Then R_1 is

adjusted until the whistle is barely audible, giving way to a throbbing noise, which again finally gives way, and pure reception comes in. When the true Flewelling effect is obtained the good signal strength and mellow tone will be appreciated.

As already indicated, the circuit is critical, and it is perhaps best to use a frame aerial as shown by the dotted lines in Fig. 162. But it is the general principle we want you to understand rather than to arrange and work the circuit.

Originally in the *Armstrong circuit* the intermittent damping previously referred to was introduced by a separate oscillating valve coupled to the circuit in such a way that the oscillations produced by this valve opposed at intervals the received oscillations in the grid circuit of the main valve and so reduced the tendency to oscillate, producing those periods of extreme sensitiveness already mentioned. By the introduction of additional circuits the separate valve was then omitted, and the one valve made to act in both capacities. We need not, however, give details of the circuit.

4. Three Modern Single Valve Circuits.

The three circuits which follow are suited to modern broadcasting conditions and will give you loud telephone signals on your local station and the " National " together with some continental stations.

(1) The first circuit is shown in Fig. 163 and uses plug-in coils, L_1 being the aerial coil and L_2 the reaction (moving) coil. Selectivity is obtained by using for L_1 a "tapped" coil generally called an " X " coil (see again Fig. 59): the aerial is joined to one of the tappings—the one which gives the best result being found by trial. The receiver is tuned to the required station by adjusting the variable tuning condenser C_1, which has a capacity of ·0005 microfarad. The fixed grid condenser C_2 has a capacity of ·0002 microfarad, and the grid leak a resistance of 2 megohms. The simple " on-off " switch in the lead from the filament to the

low tension positive serves to " put on " or to " disconnect " the set so that it is not necessary to disconnect the leads to either the H.T. or L.T. batteries when the set is not in use. Note that in this circuit we have joined H.T. – to L.T. – (as already mentioned, this is often done).

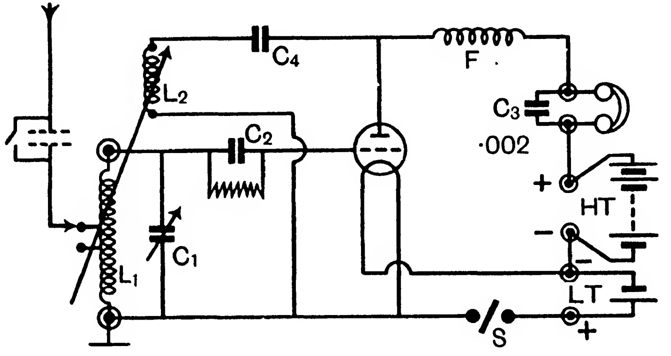


Fig. 163.

Magnetic reaction (moving coil) is used, but it will be noted that a small fixed condenser C_4 of ·001 microfarad capacity and a high frequency choke coil F have been inserted as shown: this, as already mentioned in the Reinartz circuit, keeps any high frequency currents away from the telephones, but they can " work through " C_4: at the same time " body capacity " alterations when manipulating L_2 are minimised. A detector type of valve should be used, the values of H.T. and L.T. being as indicated by the valve manufacturers.

The coil values will depend on the wave length of the station required. A No. 60X coil may be used for L_1 and different values should be tried for the reaction L_2 starting with, say, a 30 or 35. For long waves a 250X coil may be used for L_1 with a 100 coil for L_2, the latter being again found by trial.

Tuning in a station is done as already indicated. It should again be noted that when reaction has been adjusted,

for best results in receiving one station, it is invariably necessary to alter it again if the aerial tuning condenser C_1 is changed to get another station, for more reaction is required the longer the waves that are being received.

(2) Fig. 164 gives another modern circuit embodying several of the points which have been mentioned in previous circuits and, with what has already been explained, a careful examination of the figure should make everything quite clear.

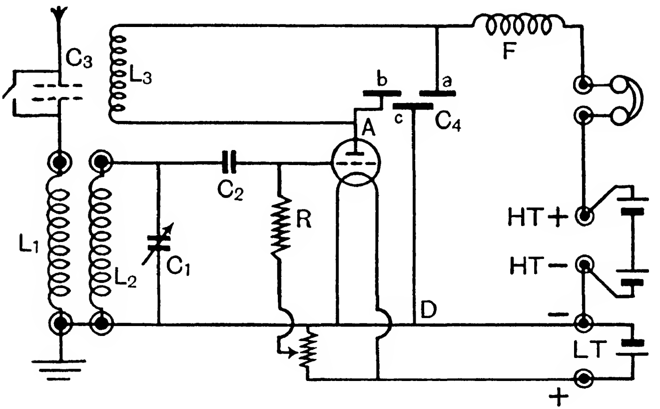


Fig. 164.

Plug-in coils of the ordinary type are used in this case, the aerial being " coupled " as in the second circuit of Art. 2. The reaction coil L_3 may be fixed but is often moving (see Art. 1), the reaction being delicately controlled by the condenser C_4: this condenser in this circuit is a " differential " one (page 70) of capacity ·0001 microfarad, *a* and *b* being the fixed plates and *c* the moving plate: moving *c* out of *b* and into *a* increases the capacity in the path AL_3acD. A potentiometer (400 ohms) has been joined across the low tension leads and the grid leak (2 megohms) is joined to the variable contact on it so that the potential of the grid of the valve may be adjusted. A

series condenser C_3 of ·0003 microfarad capacity is in the aerial: this is variable and is used for the control of the selectivity.

Coil values may be L_1 35, L_2 50, and L_3 50 or 60, determined by trial: for the long waves the values may be L_1 100, L_2 200 or 250, and L_3 150 or 200.

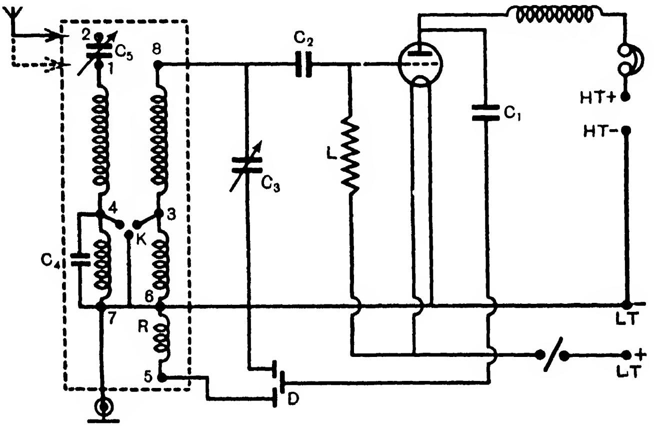


Fig. 165.

(3) The third circuit shown in Fig. 165 uses a Telsen dual range aerial coil (Fig. 67) instead of plug-in coils. This coil can be used for either the medium or the long waves, the change being done by a three point wave change switch. As already mentioned in Chapter IV., this is done in many tuners by short circuiting out the long wave coils, thus reducing the inductance when the medium waves are being received. The reaction winding is incorporated in the coil, reaction being controlled by a differential reaction condenser.

From what has been said you will understand the circuit from the figure. The coils on the left within the dotted lines represent the Telsen tuner, R being the reaction coil joined *via* the differential condenser D (·0003 microfarad), and the small fixed condenser C_1 (·001 microfarad) to the

plate of the valve (see Art. 5, below). The grid leak L is of 2 megohms resistance: note that it is joined between the grid and low tension positive. The grid condenser C_2 is of ·0003 microfarad capacity and the tuning condenser C_3 ·0005 microfarad. Selectivity is improved by the condenser C_4 (·0003 microfarad): for further selectivity a small semi-variable condenser C_5 can be put into the aerial or cut out if necessary by a shorting arrangement (its capacity should be variable from about ·00002 to ·0003). By means of the switch K the long wave coils can be "shorted" when the medium waves are required.

This is a very efficient single valve circuit and you should carefully think over the connections and the action.

5. Decoupling Resistances and Condensers.

There is one point we want you to notice, in passing, about some of the preceding circuits, although the full importance of it will only arise when we are dealing with multivalve circuits.

Notice that in Figs. 163–165 a choke (which has a fair inductance) is put in between the plate of the valve and the high tension positive, and a condenser of some sort is also in between the plate and earth. The choke or inductance acts as a barrier, as already explained, to any high frequency currents in the plate circuit: it keeps them back from the battery and telephones, forcing them to "work through" the condenser to earth (H.F. currents can work through a condenser).

Some such arrangement is largely used in multivalve sets and they are referred to as **decoupling** resistances and condensers. In multivalvers the plates of all the valves are joined to the high tension positive either directly or indirectly. The battery usually has a fair resistance to high frequency current and it feeds back such currents to the various valve plates causing oscillations, "motor boating" (see later), and making the set unstable. Motor boating is the name given to a low note quite audible in the loud speaker (and very irritating) due to this feed back from the battery to the various plates. It mainly

occurs if there are defective cells in the battery or if the latter is run down: it sometimes occurs if an eliminator is used (Chapter XI.) in which separate plate feed resistances are not provided.

" Decoupling " prevents the above, for it keeps any high frequency current in the plate circuit away from the battery, causing it to take the condenser path to H.T. — and earth. Note that we have said decoupling *resistances*. In multivalve sets chokes are used for "coupling" *one valve to the next* (see Chapter XI.), but resistances are mainly used for this " decoupling " business (except in the output stage or when the H.T. supply is big). Fig. 165 (*a*) shows a decoupling resistance R (and condenser C) used in the plate circuit of a valve. Decoupling the detector valve is perhaps the most important: in this case R may be about 20,000 ohms and C 2 microfarads. R may be larger with advantage if it does not cut down too much the voltage on the plate (from the H.T. battery), and C may then be less: as a general guide R in ohms multiplied by C in microfarads should be of the order 35,000 to 45,000.

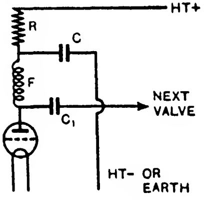


Fig. 165 (*a*).

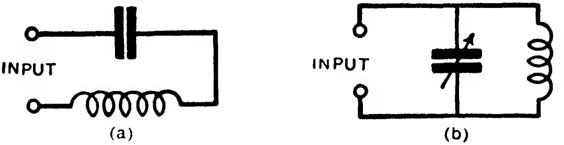


Fig. 166.

6. Wave Traps: Acceptor and Rejector Circuits.

If a set is being used only a few miles from a powerful transmitting station the latter sometimes spoils reception from a wanted more distant station: in such a case a wave trap to cut out the unwanted station proves a boon and a blessing.

If a variable condenser and an inductance be arranged in series as indicated in Fig. 166 (*a*), the circuit will of course have a certain frequency depending on the values of the inductance and the capacity. Now if the inductance be large compared with the capacity, and if the resistance be low, it can be shown that *this circuit will readily allow the passage of oscillations of the same frequency as itself*, but will strongly oppose the passage of oscillations of any other frequency. It is evident then that a circuit like this might, for example, be tuned to the unwanted station and coupled up to the receiving set in such a way that the unwanted signals would find an easy by-pass through it, leaving the wanted signals, which are of a different wave length and frequency, to pass on to the receiver. A circuit of this type is called an **acceptor circuit.**

Again, if the variable condenser and the inductance be arranged in parallel as shown in Fig. 166 (*b*), it can be shown that *the circuit will readily allow the passage of oscillations of a different frequency to itself*, but will strongly oppose the passage of oscillations of the same frequency as itself. It is evident then that a circuit like this might, for example, be tuned to the unwanted station and coupled up to the receiving set in such a way that it blocked the unwanted signals and prevented them from affecting the receiver, leaving the wanted signals to pass through to the receiver. A circuit of this type is called a **rejector circuit.**

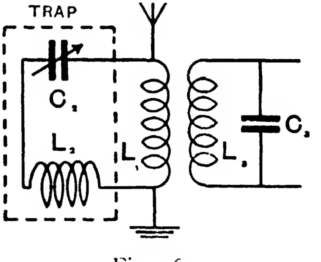


Fig. 167.

Fig. 167 indicates one method of coupling up a wave trap of the acceptor circuit type to a receiver, using inductive coupling. The trap, consisting of the coil L_2 and variable condenser C_2 in series, is tuned to the unwanted station and joined across the aerial coil L_1. Signals arriving at the aerial from the unwanted station find an easy

by-pass *via* C_2L_2, so that the receiver apparatus on the right of L_1 in the figure is not affected by these signals and can be tuned in to the wanted signals by adjusting C_3, and so on in the usual way. The coils L_1 and L_2 should always be kept well away from each other, and preferably at right angles.

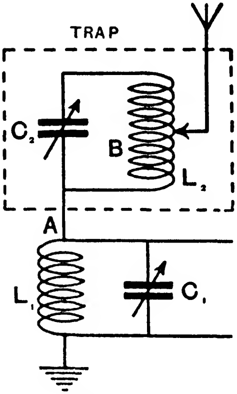


Fig. 168.

Fig. 168 gives a method of coupling up a wave trap of the rejector type. The trap, consisting of the coil L_2 and variable condenser C_2, is tuned to the unwanted station and put in series with the aerial as shown (it is sometimes called a **series rejector**). It therefore blocks these interfering oscillations, but allows the others to pass on to L_1. Of course in practice the procedure is as follows: The aerial is joined to A and the *unwanted* station is tuned in on the set: the trap is then joined up as in the figure, the aerial being now joined to B, and C_2 is adjusted until the unwanted signals disappear: the trap is now left at this, and the set tuned in to the wanted station.

You should make one: 60 turns of wire on a vulcanite tube of 2½ inches diameter, and a variable condenser of ·0005 microfarad capacity suggests a starting point from which you can experiment.

7. The Principle of "Band-Pass Tuning."

The demand for selectivity, *i.e.* the reception of one station clear of others has, as already indicated, led to the incorporation of several devices in modern receivers, and in addition to those which have been dealt with, the principle of the *band-pass circuits* may be briefly referred to, for "band-pass tuning" is being largely used in some form or other in the receivers of to-day.

We have seen that when speech or music is being sent out the station broadcasts other frequencies (known as side-bands) in addition to the carrier wave frequency. These are spaced on both sides of the carrier frequency and may extend to several kilocycles. Selectivity in a receiver is essential now that so many stations are broadcasting, but in aiming at very marked selectivity we must try to avoid cutting off those "side" frequencies which differ most from the carrier frequency —spoken of as **side-band cut-off** — or of reducing their strength so much that the *quality* of the reception suffers.

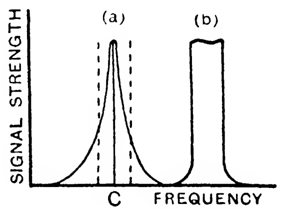


Fig. 169.

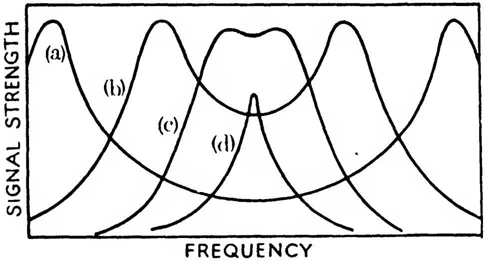


Fig. 170.

In tuning in a set we really make the receiver in resonance with the signal coming in, and (*a*) in Fig. 169 might be the resonance or signal strength curve for a set with razor-edge selectivity, but it will be noted that there is a definite " cut off " of those side-band frequencies differing most from the carrier frequency C: a moderately narrow but flat-topped curve like (*b*) would be better, for such a set would accept the particular station and reject others, yet there would be a minimum side-band cut off for the station selected ((*b*) is accepting all the frequencies, carrier and side-bands, between the dotted lines).

The *band-pass filter* really aims at securing selectivity and at the same time avoiding marked cutting off of the side bands of the station to which the set is tuned, and it does it by a suitable coupling between the aerial and the secondary (coil and condenser) circuit joined to the valve, etc. It is merely an extension of the coupled tuning arrangements already dealt with.

To explain exactly the "why" of the band pass necessitates mathematics, but the following may help you. If we have two coupled circuits of frequency f and we set up oscillations in them, oscillations of *two* frequencies are produced, one greater and the other less than f. The result is that the resultant oscillation rises and falls, *i.e.* exhibits what we might call "beats": the time between the beats depends on how the circuits are coupled. The real cause of the two frequencies is that the mutual induction between the circuits affects the self-induction of each circuit. Now further, if we plot a resonance curve (like Fig. 169) for such coupled circuits, by measuring the current produced when an oscillating E.M.F. is applied and its frequency varied, the curve usually has two maxima or "peaks," and the coupling can be so arranged that the two peaks merge more or less into each other, producing a flat-topped curve with steep sides. The circuit then passes a " band " of frequencies (in practice, the carrier and side bands) but refuses others. This is the idea of the band-pass filter.

The curve (*a*) in Fig. 170 is the " response " curve when the coupling between the two coils is very tight (coils close together). There are two humps or peaks (this means that you would be able, in the case of a receiver, to get a station at two different settings of the tuning condenser). If the coupling is made looser (coils further apart) the two peaks move nearer together like curve (*b*). With still looser coupling we get curve (*c*)—a more or less flat-topped curve with steeper sides. With a still more loose coupling the strength of the signal falls off (the peak is not so high) but the tuning is very sharp. Now the band-pass principle is to *so arrange the coupling* that a curve after the style of

(*c*) is obtained: a receiver giving this flat-topped curve would pass a band of frequencies (carrier and side bands) from the wanted station and reject others: it would be selective but would not wipe out the side bands so much as to spoil the quality of the reception. Fig. 169 (*b*) is more *ideal*. The present station separation is about 10 kilocycles (really 9). Suppose that the distance between the dotted lines of Fig. 169 represents 10 kilocycles—5 kilocycles on each side of C, the station to which the receiver is tuned. Then a coupling which resulted in the curve (*b*) of Fig. 169 would mean that frequencies more than 5 kilocycles on either side of C would cause no interference, yet a range of 10 kilocycles (carrier and side bands) from the wanted station would be accepted without cut-off.

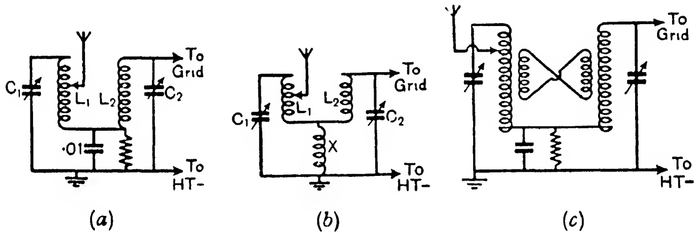


Fig. 171.

Various band-pass arrangements—which are, after all, merely variations on the original "coupled" aerial and secondary tuned circuits already dealt with—are in use in modern high-grade receivers, the differences being in the way the two tuned circuits are coupled. There are three methods in common use indicated in Fig. 171. In (*a*) a coil in the aerial is tuned by a condenser, another coil in the grid circuit is tuned by another condenser, and the two circuits are coupled by a ·01 fixed condenser. In (*b*) one coil X is common to both tuned circuits. In (*c*) a combined method of coupling the circuits is used: this is often referred to as the "link method" and is largely in use to-day.

Band-pass methods, then, aim at getting coupled circuits having more or less square topped resonance curves, and they have proved very successful in this respect in practice. In multivalvers the methods demand, however, extreme accuracy in the "matching" of the inductances and the ganged condensers in the circuit. The present-day practice (to avoid the effects of side-band cut-off) in cases where band-pass tuning is not used, is to allow a certain amount of this distortion in the high frequency stages and then to correct for it in the low frequency stages: thus if the high frequency stages enhance the bass, then it is arranged that the low frequency stages boost the treble, so that a uniform overall result is obtained.

CHAPTER XI.

MODERN MULTIVALVE RECEIVERS.

1. Amplifying Valves.

As already explained, a valve may be used to amplify or magnify the weak signals just as they arrive at the aerial, *i.e.* before they are passed on to the detector valve: this is called *high frequency amplification*, for the signals are magnified at high or radio frequency. A valve may also be used to amplify the signals after they have passed through the detector valve: this is called *low frequency* or *audio frequency* or *note amplification*, and is used to increase the volume of sound and to enable a loud speaker to be used. Although there are certain special features about high frequency amplification and others about low frequency amplification, the general principle, as already indicated, is much the same in both. It will, of course, be understood that for high frequency amplification the various pieces of apparatus must be suitable for high frequency work, whilst for low frequency amplification they must be suitable for low frequency work.

In the case of a two-valve receiver, consisting of a high frequency amplifying valve followed by a detector valve, the action is briefly this: The varying potential differences set up in the aerial inductance are applied between the grid and filament of the amplifying valve, which valve is, of course, arranged to work on the steep part of its characteristic. Corresponding *but magnified* changes in current are produced in the plate circuit of this valve, and as this circuit contains either a resistance or inductance or condenser, corresponding *but magnified* variations in the potential differences across them are produced. These amplified potential differences are applied to the grid of the second valve (which valve is, of course, arranged to

work as a detector), and the action is then the same as in the case of the single valve (detector) circuits dealt with in the last chapter.

It is clear that two or three stages of high frequency amplification might be used. In practice, however, there is a limit to the number of stages owing to the tendency to set up local oscillations.

In the case of a two-valve receiver, consisting of a detector valve followed by a low frequency amplifying valve, the outline of the action is just the same as in the preceding. The low frequency *unidirectional* variations produced in the plate circuit of the detector valve are applied to the grid of the low frequency amplifying valve, with the result that on the output or plate circuit of this valve we have corresponding low frequency variations, but, of course, magnified. These are passed on to the telephones or loud speaker. Similarly, more than one low frequency amplifier may be—and often is—used.

A glance at Figs. 131, 132 will show that the bigger the amplitude of the oscillations (*i.e.* the bigger the grid swings) applied to the input side of a detector valve, the better is the valve acting as a rectifier. Signals from a distant station may be too faint for efficient detection, but with a high frequency amplifying valve in front of the detector valve the amplitude is so increased that detection becomes efficient. We have said that high frequency amplification increases the range of a receiver, *i.e.* enables distant stations to be received.

Since low frequency amplification magnifies the signals of audible frequency which the detector would normally pass on direct to the telephones, it is clear that low frequency amplification increases the sound in the telephones.

The main features of the various coupling methods between valves will be dealt with in the sections which follow, and as you are probably more interested in good volume and loud speaker reproduction from a few stations than in searching for far distant stations, low frequency amplifying circuits will first be considered. Further, to make the matter simpler we will first deal with *triode* valves.

2. The General Idea of Coupling.

Before we go on to actual methods of coupling valves it will help you wonderfully if you first consider Figs. 172 and 173.

We want to pass on the pressure variations in the plate circuit of the first valve to the grid of the second, and in Fig. 172 we have drawn a line AB to represent a wire joining this plate and grid. Now as a matter of fact this is hopeless because the *grid* of the second valve is joined to the positive pole of the high tension battery: in fact it practically becomes a plate, and the valve will not work. To speak more scientifically, there is a certain steady plate current in the plate circuit of A from the H.T. battery when no signals are on, causing a steady potential drop across the resistance in that circuit, and this steady potential would be applied to the grid of B thus making B go altogether on to the wrong part of its characteristic. What then are we to do? We must get the pressure variations—the impulses—to pass along from the plate to the grid, and at the same time we must protect the grid from the positive pole of the high tension battery.

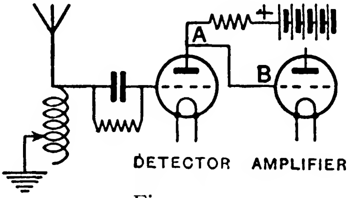


Fig. 172.

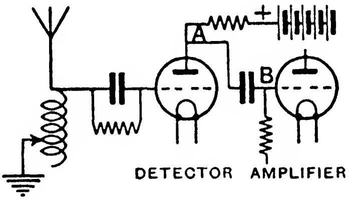


Fig. 173.

Well now we know that a condenser will allow an alternating or a varying or a surging current to "work through" it but will not allow a steady current to "flow" through it, and this suggests that one method would be to put a condenser in the path AB as shown in Fig. 173: this condenser will let the magnified surges from the plate of

the first valve work through to the grid of the second, but it will stop any steady current from the plate battery getting along to the grid, and that is exactly what we want.

Another method that suggests itself is this. We could have a primary coil in the plate circuit of the first valve, and up against this a secondary coil joined between the grid and filament of the second valve (Fig. 174). In this case the current variations in the plate circuit of the first valve cause corresponding variations to be induced in the secondary coil, and these are applied between the grid and filament of the second valve, but the grid is in no way connected to the high tension battery, and this is what we require.

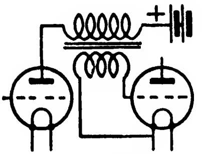


Fig. 174.

We can now go on to the various coupling methods in detail.

You will note that in the Sections 3, 4, and 5 following we sometimes give you the complete circuit but sometimes we only draw the particular part of it which we want you specially to notice: this is less confusing, and enables you to concentrate on the one thing we happen to be dealing with. You will meet them all again in complete circuits.

3. Coupling a Low Frequency Amplifying Valve to a Detector Valve.

The first arrangement we will consider uses a transformer: hence it is referred to as **transformer coupling.**

In Fig. 175, D is the detector valve and A the low frequency amplifying valve. The primary P of the transformer is put in the lead from the plate of D to the positive of the high tension battery, and the secondary S is joined to the grid of A and to the negative of the low tension battery. It is essential to work the amplifying valve on the straight, steep part of its characteristic curve and with most modern valves, to ensure this, it is necessary to give the grid a certain negative bias. To this end a few dry cells (grid battery) are inserted at X, the negative terminal being joined through S to the grid of A.

Note that the grid leak R of the detector valve is joined to the positive of the low tension battery as in the single valve circuits of Chapter X. Further, as one valve is working as a detector and the other as an amplifier, different potentials (given by the makers) are applied to the plates from the H.T. battery. Moving coil reaction is shown but capacity methods may, of course, be used.

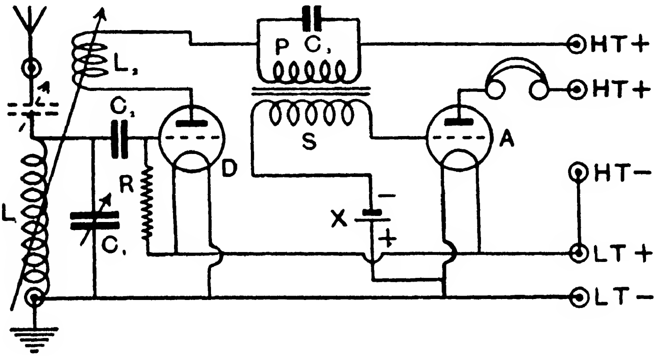


Fig. 175.

Suitable condenser values are for C_1 ·0005, for C_2 ·0003 microfarad. For the broadcast band of wave lengths, L_1 may be a No. 35 or 50 coil and L_2 a No. 50 or 75. For long waves a No. 150 coil for L_1 and a No. 200 for L_2 will be suitable. It is always well to keep the reaction coil as small as possible. A suitable value for the grid leak R is 2 megohms.

The tuning in of this circuit is carried out in much the same way as already indicated for the circuits in Chapter X. Selectivity is improved by using a small condenser (dotted lines) in the aerial (capacity – maximum ·0003), and by using a tapped aerial coil (X coil).

Transformer coupling gives the best volume for loud speaker work, but transformers pass on certain frequencies better than others so that the amplification of different note frequencies is not the same, and this leads to distortion in speech and music, although with the well-made

transformers of to-day this is not serious. There is sometimes rather too much amplification of the notes of high frequency (treble): this can be reduced by joining a high resistance (about half a megohm) across the secondary winding.

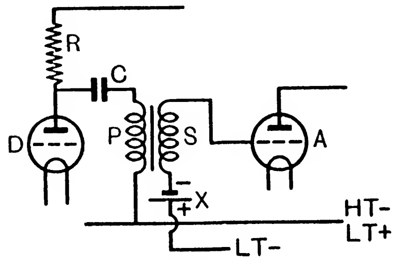


Fig. 176.

Sometimes there is a too marked falling off in the amplification of lower frequency notes (bass): to remedy this care must be taken that the resistance (see below) of the primary coil is large compared with the slope resistance or impedance of the detector valve.

Since the primary P is in the plate circuit of D the direct current through it may be such as to have a detrimental effect on the iron core of the transformer, thus decreasing the inductance of the primary (and causing a falling off of the bass). This is partly avoided by using a transformer with a core of special alloy, but often the circuit is modified, as shown in Fig. 176, where R is a suitable resistance and C a condenser of about ·1 microfarad, which does not allow direct current to flow through the primary. The resistance R should have a value of the order about $2\frac{1}{2}$ to 3 times the impedance of the valve. This is referred to as the **parallel feed** method of arranging the transformer.

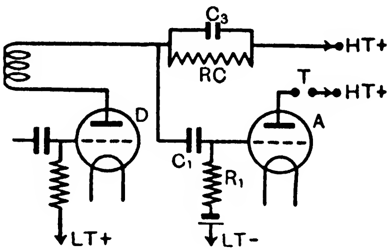


Fig. 177.

Another method of coupling known as **resistance capacity coupling** is shown in principle in Fig. 177. The resistance

RC is in between the plate circuit of the detector valve D and high tension positive, and the condenser C_1 connects the plate of D to the grid of the amplifying valve A. In this case the rectified current variations produced by D cause pressure variations on RC, and these are applied to the grid of A through the coupling condenser C_1.

The resistance favoured for RC depends on the circuit and the valve employed. A general value of 100,000 ohms is sometimes used, although some manufacturers often employ a higher value. A general guide is that it should be of the order 3 to $3\frac{1}{2}$ times the value of the impedance of the valve: this we have found to be a good general rule. The C_1 condenser capacity will depend upon the plate resistance: if this is between 30,000 and 100,000 ohms a capacity of the order ·01 is suitable, whilst for lower values of the resistance a capacity of the order ·05 to ·2 is better.

With this coupling condenser it is necessary to use a resistance R_1 between the grid and filament to act in a similar way to the grid leak of a detector valve. This high resistance R_1 is joined to the *negative* terminal of the grid bias battery, the positive of which is joined to low tension *negative* (note that the grid leak of D is joined to low tension *positive* as usual). The resistance R_1 sometimes has a value of one megohm, although a smaller value—·5 or ·2 megohm—invariably gives better results: in fact a good working rule is about 4 times the plate resistance, so that if the latter is, say, 60,000 ohms, R_1 may be about 240,000 ohms, or about ·24 megohm. A greater high tension voltage is necessary in the plate circuit of D in order to compensate for the fall in voltage across RC.

As already indicated one objection to transformer coupling is that it may result in unequal magnification of different frequencies and therefore produce a certain amount of distortion. In resistance capacity coupling we get uniform amplification; it amplifies signals embracing frequencies from about two hundred up to several thousand cycles per second without displaying any preference for any particular frequency. Against this advantage there is

the disadvantage that resistance-capacity coupling does not give the amplification that transformer coupling gives.

Yet another method of coupling—known as choke coupling or **choke-capacity coupling**—is also employed (Fig. 178). A choke or choke coil used for low frequency coupling is simply a coil of wire of low resistance wound upon an iron core and having therefore a large amount of inductance: it must have a high inductance and as low a self-capacity as possible. The value of R_1 should be from 10 to 12 times the valve impedance.

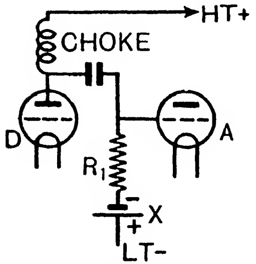


Fig. 178.

The explanation of the action of this coupling is much the same as in previous cases. In a general way whilst choke coupling does not give the amplification that transformer coupling does, from the point of view of signal strength it is superior to resistance-capacity coupling: on the other hand, choke capacity is inferior to resistance capacity coupling from the point of view of pure reproduction, but a little superior to transformer coupling in this respect.

4. Coupling a High Frequency Amplifying Valve to a Detector Valve.

Perhaps the most popular method of coupling a high frequency amplifying valve to a detector valve is that known as the **tuned anode coupling** method shown in Fig. 179, where A is the high frequency amplifying valve in front of the detector valve D.

In the plate circuit of the valve A is a coil L_3 and a variable condenser C_2 in parallel with it. For the broadcast band of wave lengths C_2 may be ·0002 microfarad capacity (·0005 microfarad for longer waves); a suitable coil for L_3 is a No. 50 or 75 for the broadcast band.

Reaction is obtained by coupling the coil L_2 in the plate circuit of the detector valve D with the aerial coil L_1. There is less tendency to cause interference with other listeners in the vicinity if L_2 be coupled with the anode

coil L_3 instead of with the aerial coil L_1, but results are not so good. Capacity control reaction can, of course, be used.

It should again be noted that the grid leak R of the detector valve is joined to the *positive* terminal of the filament battery. The grid of A, with some valves, has to be given a certain negative bias by means of a grid battery just as was done with the amplifying valves of Art. 3.

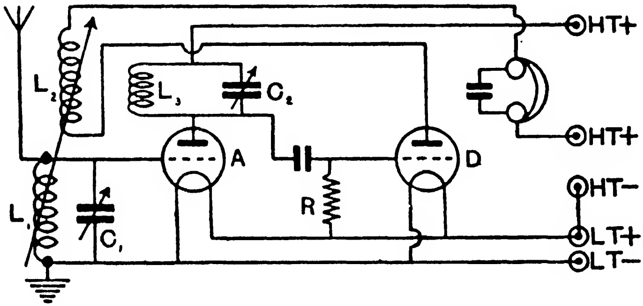


Fig. 179.

In this arrangement both the L_1C_1 circuit and the L_3C_2 circuit are tuned to the desired frequency (and wave length). The varying (high frequency) potentials applied to the grid of the amplifying valve A (which works on the straight part of its characteristic) produce amplified oscillations in the plate circuit of A, *i.e.* corresponding (amplified) potential differences are set up across L_3C_2: these are fed to the grid circuit of the detector valve (arranged to work as a rectifier), the plate circuit of which includes the telephones.

The tendency for the high frequency triode valve to oscillate is the chief trouble encountered in this circuit: this defect is dealt with in Art. 5. Ordinary triodes are rarely used now for H.F. amplification, screened grids being mainly employed.

A modification of the circuit of Fig. 179 is shown in Fig. 180, in which the anode or plate coil is tapped—a device which is beneficial from the point of view of selectivity.

A further modification is indicated in Fig. 181 known as the **parallel-feed** or **tuned grid** circuit. In it a choke L_1 is placed in the circuit between plate and H.T. +, the tuned circuit (coil and condenser in parallel) L_2C_2 is in between the grid and filament of the detector valve, and a coupling condenser C_1 is employed in the usual way. The principle of the action is the same as that already given in preceding pages, and you should think this out carefully before proceeding further. LS is the position of the loud speaker or telephones in the plate circuit of the last valve.

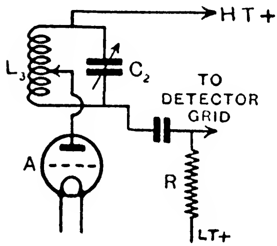


Fig. 180.

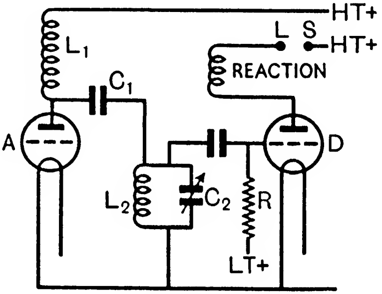


Fig. 181.

You will notice that the aerial circuit (not shown in these figures) and the plate or anode circuit of the valve A have to be "tuned." In modern receivers the two tuning condensers are invariably "ganged" so that they are adjusted simultaneously by the movement of one knob on the panel.

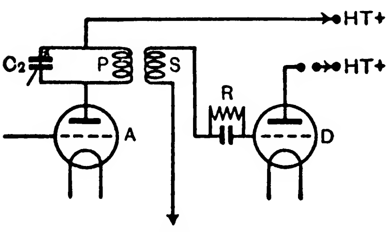


Fig. 182.

Another method of coupling known as **transformer coupling,** is shown in Fig. 182. A transformer for this type of

work, *i.e.* for use with high frequency amplifying valves, is called a *high frequency transformer*. It works on the same principle as an L.F. transformer, the essential difference being that an H.F. transformer usually has an air core, but couplings with iron-dust cores are in use.

Now referring to Fig. 182, the secondary S of the transformer in the plate circuit of the amplifying valve A is connected, as indicated, between the grid and filament of the detector valve D. Since the aim is to apply as high a voltage as possible to the grid of D, the secondary S should be tuned as well as the primary P, but it is found that with the tight coupling which exists between P and S in practice (P and S are *fixed* close together and the coupling is said to be *tight coupling*) the one tuning condenser C_2 in the primary tunes both P and S. The capacity of C_2 is about ·0002 microfarad.

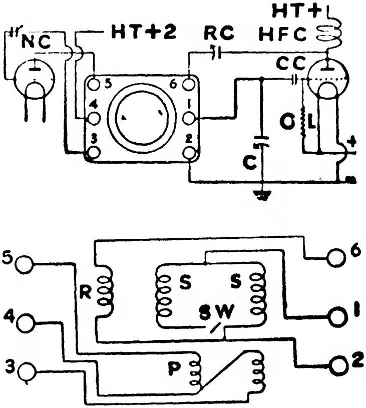


Fig. 183.

The grid leak R of the detector valve in this circuit may be placed across the grid condenser, for S is quite separate from P (and the positive high tension), and is joined to the positive of the low tension battery. A reaction coil from the plate of D may be coupled to the aerial inductance or to the transformer windings.

Many coils on the market can be used either as aerial tuners or as high frequency transformers, and, of course, several coils specially intended for the latter purpose can be obtained. Thus the Lewcos six pin dual range coil (DAP) can be used as a high frequency transformer, and is so used in many modern receivers. A diagram of the coil arrangements is shown in Fig. 183, S being the secondary

winding, P the primary winding, and the six terminals being numbered 1 to 6. It will be noted that the primary is "split," terminal 4 being joined to the middle of it.

Fig. 183 shows the transformer coupling the high frequency valve on the left to the detector valve on the right. The coil R is the reaction winding. The reaction condenser RC communicates with R *via* terminal 6, its other pole being joined to the plate of the detector valve. You will see, therefore, that the circuit of Fig. 183 utilises the capacity control method of reaction.

NC is a "neutralising condenser": its use will be explained presently. SW is a switch which is altered according to whether the ordinary broadcast band of wavelengths or the longer waves are to be used. Go carefully through the connections in Fig. 183 and you will see they are applications of the principles already dealt with.

Theory shows that a high frequency transformer with a high transformer ratio (page 98) increases the effective capacity of the tuned circuit and improves selectivity. The high frequency valve itself should have a fairly high amplification factor.

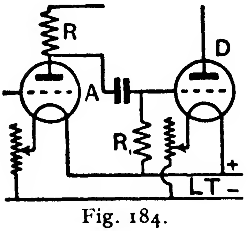


Fig. 184.

Yet another method of coupling—**resistance capacity coupling**—between the high frequency amplifying valve and the detector valve is shown *in outline* in Fig. 184, and you will understand the circuit from what has been said in Art. 3.

In still another method—**choke coupling**—a *high frequency choke* takes the place of R in Fig. 184. The action of this coupling will also be clear from preceding pages.

5. The High Frequency Stage—Oscillations with Triodes. Using Screened Grid and Variable-Mu Valves.

One of the greatest drawbacks to the use of high frequency amplifying valves of the triode type is that there is a tendency for the receiving set to start oscillating. This is due to the fact that there is often marked capacity

inside the valve between the plate and grid, and this capacity acts just in the same way as the reaction condenser which was referred to in dealing with reaction: it feeds back energy from the plate circuit to the grid circuit, and if this be excessive, oscillations are set up.

One method of partially controlling this in the early days of wireless was to insert a resistance in the tuned circuit in such a way that it produced a certain amount of damping which tended to check oscillations. Another method of controlling or *neutralising* the effect was to employ a potentiometer and to give a slight *positive* potential to the grid of the high frequency valve which will damp down the effect of the valve capacity.

But the most effective method suggested was the employment of what is called the **neutrodyne circuit,** for it neutralised the effect of the inter-electrode capacity of the valve without reducing the efficiency to the extent that the other methods did: in some form or other it is sometimes met with in the receivers of to-day, although the advent of the screened-grid valve, screens, and screened (canned) components has rendered the device almost unnecessary. It is still used, however, in transmitting.

Imagine a point could be selected on the plate side of the H.F. valve which has a potential at any instant of *opposite sign* to the potential of the plate at that instant. Imagine further that this point is joined through a variable condenser to the grid of the valve. Clearly it will be possible to feed back energy to the grid circuit *opposite* to the feed back due to the valve capacity, and by adjusting the capacity of the variable condenser it will be possible to make these two opposing influences exactly equal so that they *neutralise* each other. The impulses delivered by one will be equal and opposite at any instant to the impulses delivered by the other, so that the set as a whole will remain quiet and stable: this is the elementary principle of the neutrodyne circuit.

One type of neutrodyne circuit is depicted in Fig. 185. The coil L in the plate circuit of the H.F. valve A has a centre tapping which is joined to the positive of the high

tension battery. One end of the coil is connected to the plate of A and the other end *via* the neutrodyne condenser N to the grid of the valve. The coil L has a variable condenser C across it, and the LC circuit is tuned just as in the case of the tuned anode coupling methods previously dealt with.

A little consideration and examination of the figure will show that since the H.T. positive is joined to the middle of L (and therefore the two parts of the coil L are equal) the connections are such that by adjusting N it will be possible to make its capacity equal the plate-to-grid capacity of the valve. The feed back due to the valve capacity will thus be equal to that due to N, and as the two will be opposite in phase they will cancel and the circuit will be stable: moreover it will remain stable however C is altered, and even if L be changed for another centre tapped coil.

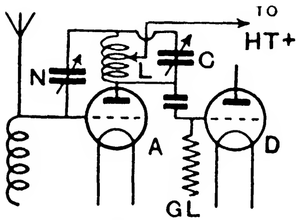


Fig. 185.

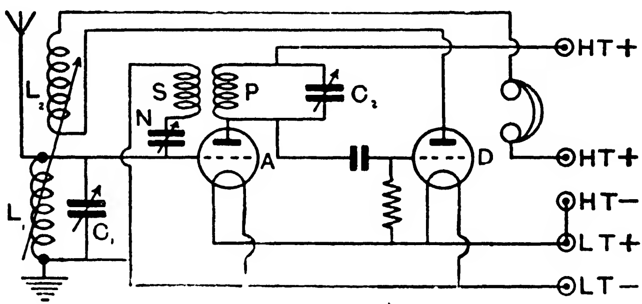


Fig. 186.

Yet another neutrodyne circuit is shown in Fig. 186. It will be seen that the primary P of a high frequency transformer is included in the plate circuit of the amplifying

valve A. The secondary S of this transformer has one end connected through a small neutrodyne condenser N to the grid of the valve and the other end connected to the *negative* lead of the low tension battery.

In working with this circuit we proceed as follows:—With the usual No. 35 or 50 for the aerial coil L_1, the aerial and earth disconnected, and the reaction coil short circuited, the condenser C_1 is set at about 10° and C_2 rotated: in certain positions the set will oscillate. Next adjust the neutrodyne condenser and it will be found that the range of the oscillations on rotating C_2 is being reduced; continue this until the set practically does not oscillate when C_2 is moved to and fro. Now set C_1 at 20°, and again rotate C_2 and, if necessary, slightly adjust the neutrodyne condenser for no oscillation. This is continued until a setting of the neutrodyne condenser is obtained, such that there is no oscillation for any positions of C_1 and C_2.

Having got the neutrodyne condenser to its correct position it is allowed to remain there, and the set is tuned in in the usual way, the aerial and earth being now connected to the set, and a No. 50 or 75 coil being placed in the reaction.

Of course, the actual feed back is not only due to capacity between plate and grid but also to stray capacities between components and between the wires connecting up to the valve. To cut down these stray capacities components are surrounded by metal screens which act as electro-static shields, whilst at the same time the eddy currents induced in the screens cut down inductive coupling between adjacent components: metal screens are also used to separate different sections of the wiring of a receiver. It must be remembered, too, that the currents in the output parts of a receiver are very much bigger than those on the input side of the receiver, and if there is any coupling between the output side and input side so much energy may be fed back as to more than wipe out all ohmic losses in the input side and make the set burst into oscillation: hence the importance of all this modern screening. These points have, however, been previously referred to.

The introduction of the screened-grid valve (in conjunction with "screening") as a high frequency amplifier in place of the triode has, however, proved the best solution of the oscillating difficulty, and before proceeding further the reader should again refer to what has been said about these valves in Chapter VIII. The anode-grid capacity of the valves is of the order less than one-thousandth part of that of a triode, so that the harmful effects of anode-grid capacity are practically absent. Apart from this the valve has a relatively high impedance and amplification factor, and the latter fact certainly improves the efficiency of the valve as a high frequency amplifier (the efficiency varies *directly* as the amplification factor and *inversely* as the *square root* of the impedance).

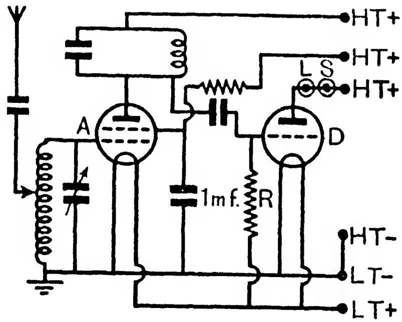


Fig. 187.

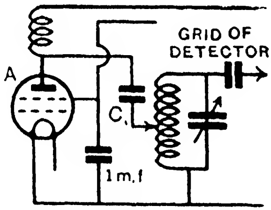


Fig. 188.

The coupling of a screened-grid valve (working as a high frequency amplifier) to the following detector valve is carried out in the same way as has been indicated for the triode. In Fig. 187 the usual tuned anode method is shown. Note that the screening grid is connected to H.T. +: the necessary voltage is given by the makers and is of the order one-half to two-thirds of the voltage on the plate. Fig. 188 gives the modified "parallel feed" or tuned grid method: the condenser C_1 has a capacity of ·0001 microfarad, and a good high frequency choke is inserted between the plate and H.T. +. Note the

decoupling condenser (Chapter X.) which must be of 1 or 2 microfarad capacity.

As already explained, despite its very strong points—its high amplification and its small inter-electrode capacity—the steep curve of the valve means a small permissible grid swing and "cross-modulation" (Chapter VIII.) sometimes arises with it. The variable-mu screened-grid valve avoids this (see page 159). The connections of the variable-mu are the same as for the screened grid, but arrangements are made for altering the bias of the grid. When weak signals are coming the grid bias is reduced. When strong signals are coming the bias is increased giving less amplification. The variable bias also acts as a volume control.

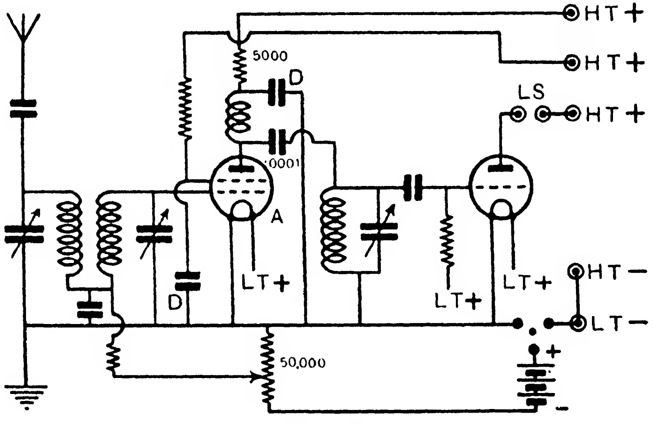


Fig. 189.

One method of getting the variable bias is shown in Fig. 189, in which a band-pass tuned circuit is given as an example: a 50,000 ohm resistance potentiometer is put across the grid battery and tapped, as shown, to the grid of the valve, and the bias on the valve is altered by altering the tapping point. A switch must be provided for cutting out the potentiometer from the grid battery when

not in use, otherwise the battery, being connected by the potentiometer, would run down. The bias required for these valves is of the order - 15 volts, but full details are given by the makers. Note the decoupling condensers (D) and resistances in the plate and screening grid circuits of the amplifying valve.

6. The Output Stage—Output Chokes and Transformers. Output Valves in Parallel.

In the previous diagrams we have assumed the telephones or loud speaker to be placed direct in the plate circuit of the last valve, between the plate of the valve and the positive of the high tension battery, but few modern speakers will give their best results if they are joined up in this way. In the first place they must be of high resistance and therefore there will be a serious drop in the potential applied to the plate of the valve: and the valve is therefore hampered in its work because it is starved of H.T. supply. Moreover, if the speaker is some distance from the set the plate current has to traverse the long leads: this means further loss of energy. There is also the drawback that being in *series* with the H.T. battery, the "speech current" (so to word it) goes through the battery, and this may lead to a low frequency note in the speaker—**motor-boating.**

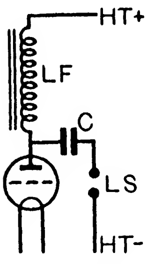


Fig. 190.

One method of avoiding these defects is to use what is called a **choke output filter,** as indicated in Fig. 190. Instead of putting the speaker direct in the lead from the plate of the *power output valve* to H.T. +, a low frequency choke L.F. of about 25 henrys inductance is placed there (output chokes specially designed for the purpose are on the market). From the plate of the valve a lead also goes to one terminal of a condenser C of capacity 2 microfarads, and the other terminal of the condenser goes to a terminal of the speaker: the other terminal of the speaker is connected to H.T. –. If the output valve is a *super-power*

valve a choke of 20 henrys will be suitable, but the 25 one may be used.

Another method is to use an **output transformer.** Frequently the transformer is tapped so that different ratios may be used to suit the output valve and speaker, for, as will be seen presently, the two must be "matched" to obtain the best reproduction (Art. 6). The primary is connected in the lead from the plate to H.T. +, *i.e.* in the position occupied by the choke in the previous method, and the speaker is joined to the secondary.

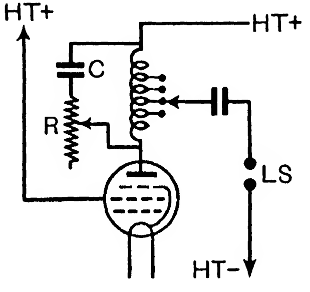


Fig. 191.

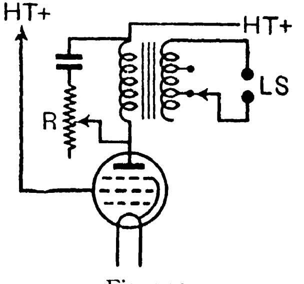


Fig. 192.

Pentode valves give great magnification and a wonderful power output but, except in the case of a few types recently placed on the market, they must be used with either a filter or transformer output to the loud speaker: "matching" between valve and speaker is all-important with the pentode. Further, as the pentode tends to emphasise the high notes, some *compensating device* or **tone corrector** may be necessary with some speakers to prevent the reproduction being too "screechy."

Fig. 191 shows one arrangement for a pentode output, the choke filter being employed. To facilitate matching a choke with several taps is advisable: each tap should be tried in turn and the one which gives the best result finally adopted. The tone corrector consists of a variable resistance R of about 50,000 ohms and a condenser C of from ·25 to 1 microfarad capacity joined as indicated across the

choke. Fig. 192 shows the pentode used with an output transformer: here the tone corrector is joined across the primary, and the condenser capacity is about ·01 microfarad. Decreasing the resistance R gives a gradual "cut off" of the emphasised high notes.

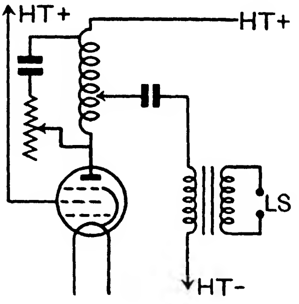


Fig. 193.

A combination of the two methods indicated above is often used with pentodes as shown in Fig. 193: here the tone corrector is across the tapped choke and the speaker is across the secondary of the transformer.

Incidentally a tone corrector may be employed with advantage across the terminals of a direct fed speaker.

If you want more volume and power from your receiver you can arrange the last stage to consist of two valves *in parallel*, if the output from your detector valve is big

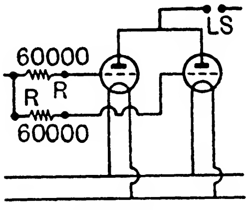


Fig. 194.

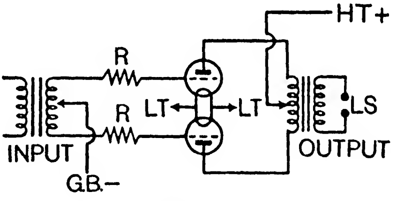


Fig. 195.

enough. The method is shown in Fig. 194, which is self-explanatory. The valves must be exactly alike, your high tension and low tension supplies must be sufficient, and it is wise to put a resistance of about 60,000 ohms in each grid circuit. The method is not much used.

A better method is to use what is called **push-pull amplification,** shown in Fig. 195: this form of amplification is fully explained in the next section.

7. Push-Pull, Quiescent Push-Pull (Q.P.P.), and Class B Amplification.

There are—and must always be—many thousands of people who are using battery-driven receivers, and there has always been a desire on the part of radio engineers to provide such with an "output" comparable with that obtained from an "all-mains" receiver, and to do it, if possible, with little or no increase in high tension battery consumption.

Now refer back to Fig. 130 and imagine that curve to represent the curve for an output valve. OA is the normal grid bias for the valve and AF is the plate current: it is the normal plate current ("rest current") when the set is "on" but no programme "on," *i.e.* no modulation. Now suppose signals arrive so that the valve receives an input after the style of P from the preceding transformer: this causes the grid potential to swing between the limits C and B and the plate current to vary between CD and BE so that our output Q is an exact replica of P but much magnified.

Clearly if we require a larger output Q we might do it by arranging to have a bigger input from the preceding transformer, *i.e.* arrange for a larger grid swing so that C moves more to the left and B more to the right. But there is a limit to this: if C gets too far to the left D comes on the bend of the curve and we get distortion, as already explained (see Fig. 137), and if B swings too far to the right we again get distortion, as was explained in connection with Fig. 138. It seems almost impossible, then, to help the battery-set owner by increasing the input signal to any marked extent.

But "push-pull" (Fig. 195) came much towards the solution. If our signal input (and grid-swing) is too large for our valve, we might divide the signal into two parts and apply each part to a separate valve, *i.e.* use two valves, and then we would be better able to handle the input signal. To divide the signal into two parts we use an input transformer with a primary as usual but with a kind of double secondary, i.e. *the secondary is centre tapped* (Fig. 195). This centre tap is really electrically connected to

the filaments. It means that the ends of the secondary are exactly opposite, *i.e.* they are 180° out of phase: put another way, the potential difference between any two corresponding points on the two branches will always be equal in magnitude but opposite in phase: put yet another way, the valves are, at any instant, one receiving "positive" (we will say) and the other receiving "negative," the two reversing for each half wave. As the voltages of the two grids are thus opposite in phase the effect on the plate current of one valve will be increasing while that of the other is decreasing. One valve "pushes," so to speak, while the other "pulls": hence the name.

As the two plate signals are 180° out of phase they must be suitably collected and combined for the final output signal. This is done by the transformer on the right, which is fitted with *a centre tapped primary*, its secondary being joined to the loud speaker. Remembering that the plate effects at any instant are opposite in phase, that one valve is "pushing" while the other is "pulling," and remembering, too, your rule for "induction" between a primary and a secondary, you will see that the final output from the secondary is about double the output of one valve.

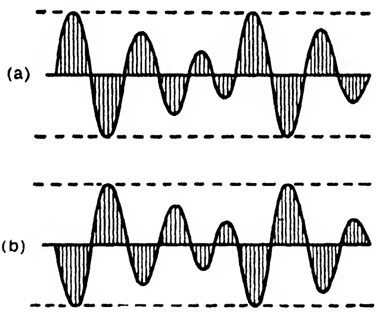


Fig. 195 (*a*).

So far so good for "push-pull": but there is a serious drawback. The top part of Fig. 195 (*a*) shows the plate current variations for one valve and the bottom part shows the variations also going on in the second valve. It means, then, that if one valve would use a current of 4 milliamperes, two would use just double that. Thus push-pull allows us to apply a larger input signal than we can give to one valve and it gives a larger output to the loud speaker, but it is a

great drain on the H.T. battery: it is too expensive to be a practical solution of our problem, and for that reason it has been very little used.

Early in 1933, however, a modification appeared, known as Quiescent Push-Pull (Q.P.P.) ("push-push," as they say in America), its aim being to so combine two high amplification valves (say pentodes) that the output will be double—or more than double—that which one valve can give, and yet the high tension consumption will be quite reasonable.

Turn again to Fig. 137. Q.P.P. arrangements are much the same as push-pull—two valves coupled in the same way, two centre tapped transformers—but the grid bias on each valve is about double the normal, i.e. *each valve is negatively biased practically right down to the point C in Fig. 137—right down to the bend of the curve.*

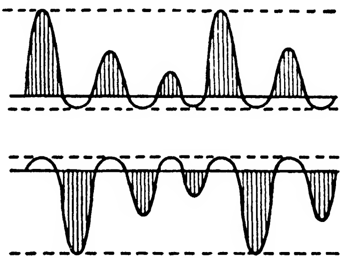


Fig. 195 (*b*).

At first sight, this statement almost seems ridiculous. If (as we said on page 169) biasing down even to A gives the distortion shown in Fig. 137, surely biasing down to C would be appalling in its results. This would be so if a single valve were in use—but it is not so with Q.P.P.

It will be noticed in Fig. 137 that as the biasing point A is brought towards the left (*i.e.* negative bias increased) the downward swings of the output Q get smaller but the upward swings are all right: thus with a biasing point at C the downward swings of Q would be *very small indeed* and the upward swings could be quite big.

Now in Q.P.P., as in push-pull, we divide the input signal between two valves by a centre tapped input transformer, but instead of getting full current variations in the plate circuit of both valves as shown in Fig. 195 (*a*) for push-pull,

we get variations as shown in Fig. 195 (*b*). Owing to the large negative bias one " loop " is almost missing in each case, *i.e.* while one valve amplifies one half of each wave of signal and practically does nothing to the other half, the second valve does practically nothing to the first half and amplifies the other half. This is clearly seen in Fig. 195 (*b*), which should be compared with the ordinary push-pull case of Fig. 195 (*a*). What it means is that while one valve is active and amplifying the other is " quiescent " (hence the name).

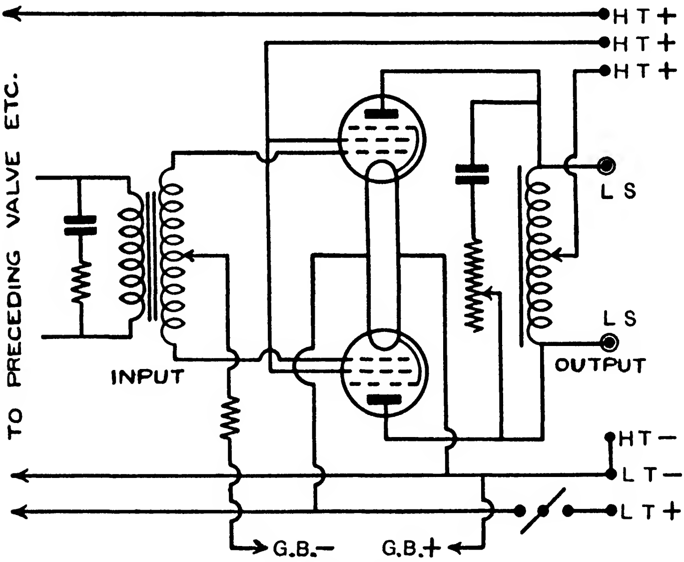


Fig. 195 (*c*).

This results in a great saving in high tension consumption, because when a valve is in its quiescent half-cycle condition the current it draws is only of the order 2 milliamperes. But the power output for the speaker is about twice that from one valve. Pentodes are very suitable for the Q.P.P. combination: Fig. 195 (*c*) shows a Q.P.P. arrangement.

We saw that in ordinary push-pull an input signal could be applied greater than could be given to a single valve because it is divided between the two valves. This applies also to Q.P.P.—but more so: we can have it nearly four times the safe input for one valve. Thus more amplifying stages can be used in front, or a high ratio "step-up" input transformer can be used: a *step-up ratio* 9 : 1 is quite usual.

In Fig. 195 (*c*) an output choke is shown instead of a transformer. The inductance of this choke must be high as practically only one-half is in use at any instant, and the resistance must be low. The variable resistance and condenser across the choke in Fig. 195 (*c*) acts as a tone corrector, but it also acts as a "safety" if the loud speaker is accidentally disconnected while the set is "on" (it restricts the sudden rise in impedance and reduces any big induced voltage).

Q.P.P. was a great advance and many wireless receivers were built up—and are still being built up—embracing it, but right on its heels came another method—a better method—now known as Class B amplification rendered possible by the advent, in the first place, of the Cossor Class B output valve. This valve was described on pages 178–180. It is no exaggeration to say that with this newest method of amplification it is possible to obtain from battery receivers an output volume equal to that of many all-electric receivers, yet with a battery consumption well within the supply of an *ordinary* H.T. battery, and less than that of many of the usual battery receivers delivering a considerably less output.

An output circuit for Class B amplification is shown in Fig. 195 (*d*): for simplicity, again, we have not drawn the high frequency and detector parts of the circuit, for these are just as usual. The general arrangement, it will be noted, is similar to Q.P.P.: we have the input transformer with its centre tap on the secondary, and the output transformer with its centre tap on the primary (or a centre-tapped output choke). Instead of two output valves, however, the single Class B valve is used: but

this is really two valves in one, and the connections to it correspond to those used with the two valves of Q.P.P.

And now for the differences. Look again at Fig. 137. If the grid is at zero potential indicated by the point O, the plate current is big—it is represented by the distance up the OY line from O to the curve, and as the negative

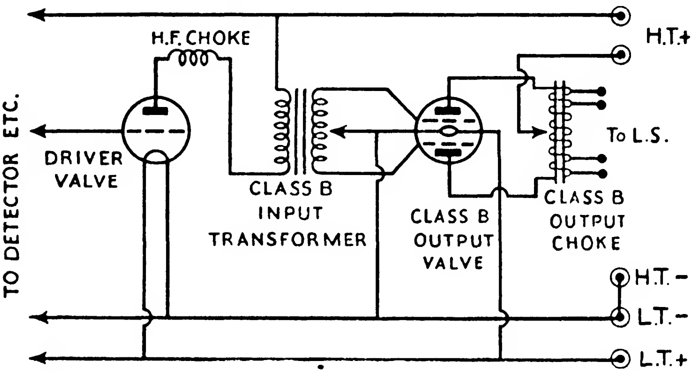


Fig. 195 (*d*).

grid potential increases the plate current becomes less. Further, in Q.P.P. we had to give a big negative bias to each grid—bias each right down to the bend of the curve (say to C) in order to practically wipe out that bottom bend of Q, *i.e.* in order to get those "quiescent" half cycles alternately with each valve (see Fig. 195 (*b*)). Now the Class B valve is different. It is so designed that it passes a very small plate current indeed *when the grid is at zero potential* (*i.e.* at O in Fig. 137). It is therefore not necessary to bias right down to C as in Q.P.P.: *no grid bias is required*, and the valve will therefore always give maximum efficiency for any given H.T. voltage without any form of adjustment.

But another point. The grid-swings to the right of O in Fig. 138, caused, as we explained, the grid to become positive and grid current flowed, which in the ordinary case tended to give the distortion shown in Fig. 138.

This grid current is about 10 milliamperes in the Cossor 240 B valve. What about this then?

Well, the grids are joined to the preceding transformer and the grid current (a "speech frequency" current since we are here past the "detector" stage) is supplied from the plate circuit of the preceding valve (*via* of course the input transformer). The first point then is that the *resistance* of the secondary of the input transformer must be *kept low.* The big "step-up" transformer used in Q.P.P. is therefore no use. A "step-down" transformer is used (secondary with *less* turns than the primary) so that the secondary resistance is low, and yet the primary can be "matched" to the preceding valve. (Note this point carefully, for transformers in wireless are usually of the "step-up" variety.) And the second point is that to make up for the loss of amplification normally caused by the use of a step-down transformer, an additional low-frequency amplifying valve is used in front of the input transformer of the Class B valve: this is called the "driver" and is really an ordinary small-power valve.

Even with the extra driver valve the high tension battery consumption of Class B is considerably less than with most ordinary battery receivers. To still further "cut" this consumption, however, it is usual to slightly over-bias the driver valve: in general the power-output of the driver is arranged to be just sufficient for the demands of the Class B valve allowing about 20 per cent. loss in the driver transformer. The correct step-down ratio of the driver transformer depends on many factors, and details are given by the valve makers. Thus with the Cossor 215 P as driver and 240 B as the Class B the (*step-down*) ratio of primary to whole secondary is 1 : 1 for 2 watts output, 1·5 : 1 for 1½ watts output, and 2 : 1 for 1 watt output (these figures mean of course 2 : 1, 3 : 1, and 4 : 1 for primary to each separate secondary). Osram, Mazda, and Mullard ratios are about 1·5 : 1 after a small power driver. As in the case of the tapped secondary of the input transformer, so with the tapped primary of the output transformer, the resistance must be kept low.

It is unnecessary to say more about the working of Class B amplification, for the general explanation is much the same as that given for Q.P.P. It gives an enormous volume for a comparatively small H.T. consumption. An ordinary output valve is so biased and worked that it takes a fairly big current all the time, even at "rest periods" when no programme is "on" (*i.e.* no modulation). With Class B this waste, we might say, of H.T. consumption is largely eliminated: during a programme pause very little current is taken, only about 1·5–2 milliamperes, and when modulation begins each half-cycle causes the current to rise in proportion only to the magnitude of the signal handled. And it can readily be fitted to any existing battery receiver.

Quality is generally good. If there is any distortion, decoupling—particularly of the detector—should be attended to. A small condenser (about ·01 microfarad) may be connected across each half of the input transformer secondary. If an output transformer is used a small condenser (about ·005) may be connected across each half of the tapped primary: with a tapped output choke these latter condensers are usually omitted.

We have mentioned the putting of a "tone corrector" across a loud speaker. With Class B, however, a better plan is to put a tone corrector on the input side of the valve (or on the output of the driver valve), *i.e.* reduce any excessive "high" before the valve, so as to maintain the economy in battery consumption characteristic of Class B.

8. Fitting Automatic Volume Control.

Reference has been made to this on page 181. In one arrangement the grid of a separate detector is put in parallel with the grid of the ordinary detector, and its plate communicates with a resistance, one end of which is earthed while the other communicates with the grid of the preceding high frequency valve, being so arranged as to give a negative potential point relative to earth. If the output is low the potential difference on the resistance is less, the negative bias of the variable-mu is reduced, and amplification is

increased. With the double-diode-triode one of the diodes is used for this. But the trouble with A.V.C. is that it works on the weakest signals and may magnify "mush." Hence "delayed A.V.C." is often arranged so that A.V.C. only operates on a reasonable signal strength. It is often done by having a small negative voltage on the plate of the A.V.C. diode so that A.V.C. is not operative until the signal strength exceeds this voltage. Fig. 195 (*e*) shows a double-diode-pentode arranged to act as detector, L.F. amplifier and delayed A.V.C. Note that a small bias is put on the valve to also act towards delayed A.V.C. Other methods of delayed A.V.C. are used.

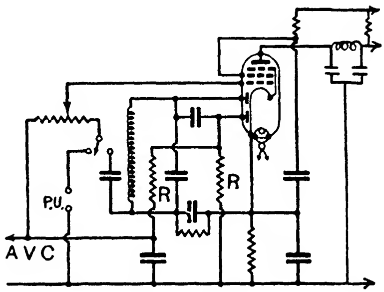


Fig. 195 (*e*).

9. Matching the Loud Speaker and the Output Valve.

We have already mentioned the **matching** of the last valve and speaker, and this is really an important point if the power output and the quality of the reproduction are to be as high as possible.

Now the full *theory* of this matching is complicated, and really demands mathematics and physics beyond the scope of this book. We will merely state the essential points, and you can apply them to your own particular case.

But we want to give you a word of warning here. Do not regard these rules as being absolutely "hard and fast" for all cases. The results you get depend on many factors, *e.g.* on the voltages and currents in the set, etc.: the results *you* like best may involve an amount of distortion, perhaps more or perhaps less than your friend can appreciate. There is no ***absolutely best*** ratio between speaker and valve

for all purposes and to suit everybody. But the rules tend to general excellence, are used within limits by designers, and will certainly result, when applied, in better reproduction.

Theory shows that in order to get the greatest amount of "*pure undistorted output*" (of course, this usual expression is really an exaggeration—there is always *some* distortion) from the last valve we must arrange that *the impedance of the plate circuit of the valve* (i.e. *the circuit containing the loud speaker*) *is twice the impedance of the valve.*

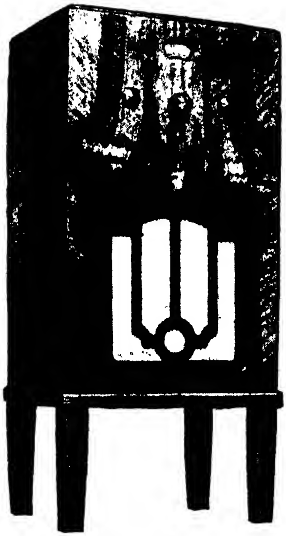
Now here a little "snag" arises, for impedance depends on the frequency, being bigger the bigger the frequency (Chapter V.). We usually, however, assume that the valve impedance does not vary with frequency, and as for the circuit impedance, we take the value to be that at a frequency of about 500. This, however, is a detail.

Now suppose we put our speaker *directly* into the plate circuit of the last valve. Then the speaker is the only impedance in the plate circuit, so that if our last valve has an impedance (which is stated by the makers) of, say, 2000 ohms, the speaker must have an impedance of 4000, to obtain the best results. If we change our last valve to one having an impedance of 3000 ohms, then we must use a speaker with an impedance of 6000, so that if we still use our 4000 speaker our results will suffer. Clearly, then, for " best " results we must either slightly modify our output circuit to " match " the new valve or use a valve of the correct impedance to " match " the speaker.

We have indicated that few loud speakers can give their best performance if put directly in the plate circuit, and have explained the use of output transformers and choke filters for the purpose. By the use of an output transformer we can readily " match " the speaker circuit and the last valve.

Let us imagine our last valve to have an impedance of 1000 ohms, and that we have a moving coil speaker, the moving coil of which has an impedance of 20 ohms. From our previous rule since the primary is in the plate or anode circuit its impedance must be $1000 \times 2 = 2000$ ohms, in

One of the many
Philco Superhet Models.
All-Mains, A.C.
Five Valves.
A.V.C. Four-point Tone Control.
Shadow Tuning.
Electro-dynamic M.C. Speaker.



Cossor.
A Four Valve Battery.
Var.-Mu S.G.
Class B Output.
Permanent-magnet M.C. Speaker.

TWO TYPICAL RECEIVERS

order to get the maximum *undistorted output* from the valve. Now the secondary of the transformer is joined to the moving coil, which has an impedance of 20 ohms, and another rule is that in such a case the *maximum power* will be developed by this combination if the two impedances—the secondary coil and the moving coil—are equal, so that the impedance of the secondary coil must be 20. Do not confuse this maximum power rule of 1 : 1 with the maximum undistorted output rule of 1 : 2.

Our next point is to find the ratio which the transformer must have to fit the above conditions. Here again we must quote the rule which theory gives: if x be the required transformer ratio—

$$x = \sqrt{\frac{\text{Impedance in Primary}}{\text{Impedance in Secondary}}}$$

$$= \sqrt{\frac{\text{Twice Impedance of Valve}}{\text{Impedance of Speaker}}}$$

$$= \sqrt{\frac{2000}{20}} = \sqrt{100} = 10.$$

Thus we require a transformer with a primary impedance of 2000 and a 10 : 1 ratio, and such a transformer can, of course, be purchased. Transformers with tapped primary coils and tapped secondary coils are on the market so that the one transformer can be used with different valves and speakers. And speaker makers often supply a suitable transformer with the speaker.

The ordinary choke and condenser filter (Fig. 190) improves reception by protecting the speaker from the direct current, and the choke has a high impedance (and low resistance), but it does not come into our " matching," and thus the valve and speaker are matched as before. A tapped choke, of course, permits of some matching. If a transformer is used in conjunction with a choke filter, the primary is merely put in the gap occupied ordinarily

by the speaker, and the matching is done as in the transformer case above.

Nowadays valve makers sometimes give the "optimum load" for the valve, *i.e.* the exact impedance that the output circuit must have in order that the valve may give the maximum undistorted output, and speaker makers sometimes give the impedance of the speaker: if the speaker is direct or choke fed these two must be approximately equal, so that it is a simple matter for any listener to "match" by choosing the correct valve to suit his speaker. And if a transformer is used it is a simple matter to "match" on the lines indicated above: use "optimum load" in the numerator of the fraction (see below).

Experience shows that as far as balanced armature speakers are concerned, there are some on the market whose impedance increases so much with the frequency (the "snag" we mentioned above) that the optimum load figures given by the valve makers are too big for them and we must allow for this by using a smaller number in matching—half the optimum load is nearer correct.

Pentode output valve matching is in some respects a separate problem. When using pentode valves the load impedance must be kept small compared to the valve impedance, otherwise, owing to the peculiar nature of the pentode characteristic, distortion will occur. However, valve manufacturers invariably give us the optimum load for these valves (usually from 5,000 to 10,000 ohms), and we can thus work out the matching. Thus the Mazda pentode AC/PEN has an optimum load of 10,000 ohms, and for the necessary transformer ratio (assuming we have a speaker of 4000 ohms) we get—

$$x = \sqrt{\frac{10000}{4000}} = 1{\cdot}6.$$

But when matching has been done in the case of the pentode it may be necessary with some speakers either to slightly mismatch the impedances deliberately or to use tone correctors to cut the treble and boost the bass: this has been dealt with. You will see from all this that the use

of a pentode output valve requires more care in design of components and choice of loud speaker, but the efficiency with a set of this sort carefully designed, is higher than is possible with a set using triode output.

10. Modern "Battery" Receivers.

You have probably, in the past, looked at some modern wireless receiving circuits in the various wireless journals and have come to the conclusion that it is a dreadfully complicated business: but now that you have mastered the preceding pages you should have no difficulty in understanding them. We will take a few modern circuits, beginning with one or two simple ones easy to construct.

A simple but very efficient two valve receiver consisting of a triode detector followed by a low frequency amplifier (a small power valve), and using plug-in coils is shown in Fig. 196: it will give your local station and many of the important European stations at good loud speaker strength. Transformer coupling is used between the valves.

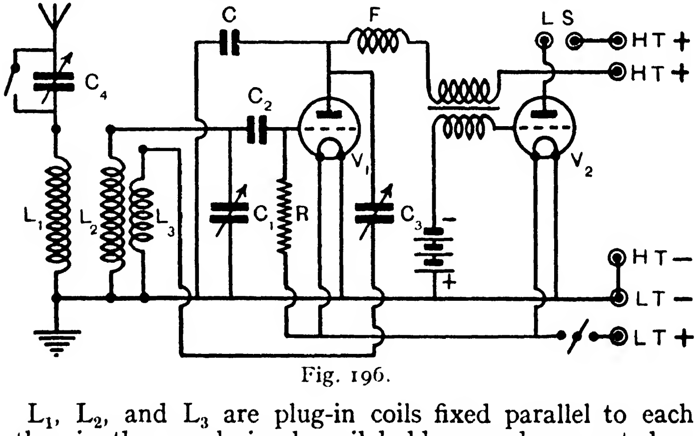


Fig. 196.

L_1, L_2, and L_3 are plug-in coils fixed parallel to each other in the usual simple coil holders, and connected as shown. For the medium waves the values may be L_1, No. 25 or 35; L_2, 60 or 75; L_3, 50 or 60. The variable tuning condenser C_1 has a capacity of ·0005 microfarad, the grid condenser C_2 is ·0003 microfarad, the reaction

condenser C_3, coupled between the plate of the detector valve and the reaction coil L_3, is a variable one, of course, and of capacity ·0003 microfarad. Note that capacity control reaction is used, not swinging coil. The aerial condenser C_4 may be of the semi-variable type of maximum capacity ·0003: it improves selectivity but decreases volume and may be cut out, as indicated, if necessary. The value of the grid leak R is 2 megohms.

The choke F is of the high frequency type: its use (with C) has been explained in preceding pages. The coupling transformer is, of course, of the low frequency type. The secondary of the transformer is joined to the *negative* of the grid bias battery, the positive of which is joined to L.T. –. Suitable valves are for V_1 a Cossor 210HL, and for V_2 a Cossor 220PA (ordinary power). The voltages (and grid bias for V_2) should be as given by the makers. The tuning-in of the receiver is carried out in the way already indicated.

The coil values given above are for the broadcast band: for the long waves L_1 should be 150, L_2 200, and L_3 150.

Another efficient circuit using, in this case, three triodes —a detector and two low frequency amplifiers—is shown in Fig. 197, resistance capacity coupling being used between the detector and the first amplifier, and transformer coupling between the first low frequency and output valves.

For the aerial tuning a Telsen aerial tuner (Fig. 67) is used: the coils are shown diagrammatically within the dotted rectangle on the left, R being the (fixed) reaction coil. On pulling out the wave change switch S the three contacts are joined together, the coils LL are short circuited and the medium waves are received: when S is pushed in the arrangement is as shown, and the long waves are received. The aerial series condenser is part of the component (in the top of it) and may be used or not as required.

The aerial tuning condenser C_1 has a capacity ·0005 mf., the grid condenser C_2 is ·0003 mf., and the coupling

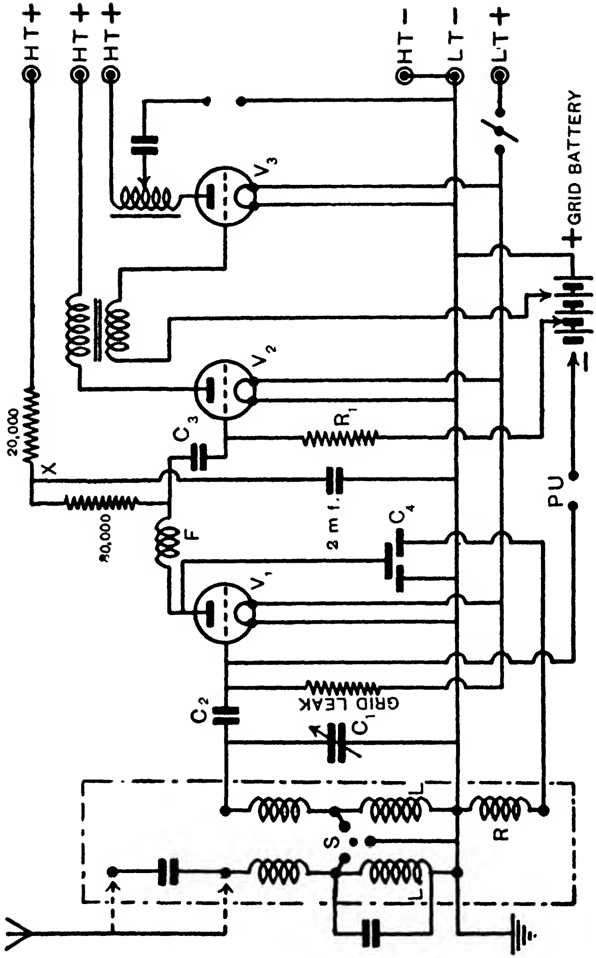

HT+
HT+
HT+
HT−
LT−
LT+
GRID BATTERY
+
V3
V2
V1
20,000
X
20,000
C3
R1
F
2 m f.
C4
PU
C2
GRID LEAK
C1
S
L
L
R

Fig. 197.

condenser C_3 is ·01 mf. Reaction is again capacity controlled by the differential reaction condenser C_4 joined to the plate of the detector valve and to the reaction coil (other fixed plate of the differential goes to L.T. –): the capacity of C_4 is ·00013 mf. The grid leak of the detector valve is again 2 megohms, and as usual is connected to L.T. +. Note that two resistances have been put in the plate circuit of the detector valve, one of 80,000 ohms and the other of 20,000 ohms, and that a *decoupling* arrangement is used, the condenser of 2 mf. capacity being inserted, as shown, between the junction X and low tension negative. Negative bias is applied to the grids of both V_2 and V_3. The " leak " R_1 is ½ to 1 megohm.

The loud speaker is choke fed instead of being direct in the plate circuit of the output valve. A power or super-power valve should be used in the output stage—*e.g.* a PM252. The letters PU merely show the path of a gramophone pick-up: this is explained later (Art. 11).

A very efficient four valve receiver, consisting of one stage of high frequency amplification followed by a detector and two stages of low frequency amplification, is shown in Fig. 198, a screened-grid valve being used for the high frequency amplification, and a power or super-power valve for the last stage.

The aerial coil L_1 is of the plug-in type provided with three tappings, as shown, to any of which the aerial is connected. Selectivity and signal strength will be different in the three cases, and you must simply try all and see which suits your purpose best. For the reception of waves up to about 500 metres a No. 60 coil will be suitable for L_1: for the longer waves L_1 must be a No. 200 or 250. The aerial tuning condenser C_1 has a capacity of ·0005 microfarad.

Transformer coupling is used between the high frequency valve V_1 and the detector valve V_2, the primary coil being shown as L_2 and the secondary as L_3. Quite satisfactory results can be obtained by using two simple plug-in coils placed parallel and close together: the coil L_2 should be a

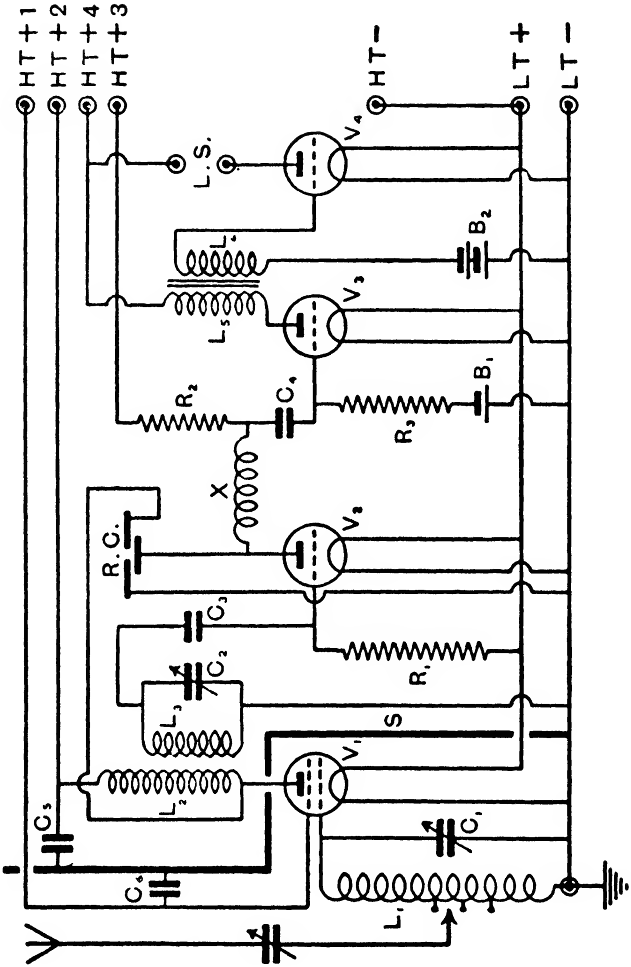

HT+1
HT+2
HT+4
HT+3
HT−
LT+
LT−
L.S.
V4
V3
V2
V1
L4
L5
L3
L2
L1
B2
B1
R2
R3
R1
C4
C3
C2
C1
C5
C6
X
R.C.
S

Fig. 198.

No. 35 or 50 and L_3 a No. 60 for the lower wave lengths, whilst for the longer waves L_2 should be a No. 150 and L_3 a No. 250.

The secondary coil L_3 forms, with the variable condenser C_2, a tuned circuit, and a suitable value for C_2 is ·0005 microfarad. The primary coil L_2 is used for "reaction" purposes, its lower end in the figure communicating with one set of the fixed plates of the differential reaction condenser RC: the moving plates of RC are joined to the plate of the detector valve V_2, and the other set of fixed plates of RC are joined to the negative of the low tension battery. One end of the primary coil L_2 is joined to the plate of the high frequency valve V_1, and the other end communicates with the positive of the high tension battery. A suitable value for C_3 is ·0003 microfarad.

The screening grid of V_1 is also joined to the positive of the high tension battery. The actual values of the high tension positive to be given to the screening grid and to the plate of V_1 depend on the type of valve used and are given by the makers: thus the plate may be connected to H.T. + 120 and the screening grid to H.T. + 80. It will be noted that the high frequency valve is "screened" from the other parts of the receiver by means of the aluminium or copper screen S. Note particularly where connecting wires "go through" and are insulated from S and where connections are actually made to S.

Coming to the detector valve V_2 the grid leak R_1 communicates as usual with the positive of the low tension battery. Resistance-capacity coupling is used between V_2 and V_3, the resistance R_2 being about ·25 megohms. X is a choke coil, and *via* X and R_2 the plate of the detector valve is joined to the positive of the high tension battery. The resistance R_3 may be about a megohm: it communicates with the negative of the low tension battery, and in this circuit is the grid biasing battery B_1, its negative pole being joined through R_3 to the grid of the first low frequency amplifying valve V_3.

Transformer coupling is used between V_3 and V_4, the primary coil L_5 of the low frequency transformer being in

between the plate of V_3, and the positive of the high tension battery and the secondary coil L_6 being joined to the grid of V_4 and to the negative of the low tension battery. The plate of V_4 and the plate of V_3 may be joined to the same positive of the high tension battery. The loud speaker should be choke fed or transformer fed instead of direct in the plate circuit, as shown here for simplicity.

A modification of the preceding four valve circuit, but using a pair of Lissen tuning coils, one for the aerial tuning and one for the coupling between the high frequency amplifying valve (screened grid) and the detector valve, is shown in Fig. 199. These two coils are alike, and the movement of one dial on the panel manipulates both the K switches for changing from medium to long waves and vice versa. R is the reaction coil and C_3 the reaction condenser (capacity ·0005 mf.). It will be noted that the second tuned circuit is in the grid of the detector valve, as explained on page 228. The two tuning condensers C_1 and C_4 (capacities ·0005 mf.) are ganged. The grid condenser C_2 is of capacity ·0003 mf. Transformer coupling is used between the detector valve and the first low frequency amplifier and again between the first amplifier and the power output valve.

The resistance shown across the secondary of the transformer is a volume control (500,000 ohms): the moving contact is connected to the grid of V_3. Negative bias is applied to the grids of both low frequency amplifying valves, and the grid leak R of the detector valve is joined to L.T. + as usual. Note the decoupling (see page 211): R_1 is about 800-1000 ohms; C_5 is 2 mf.: R_2 is about 8000-10,000 ohms; C_6 is 2 mf. A suitable value for C_7 is ·0001 mf. The loud speaker is choke and transformer fed, not direct in the plate circuit of the output valve, the choke being one of inductance 25 henrys, and the condenser of capacity 2 mf.

Fig. 200 gives the essential parts of a receiving circuit containing three valves—a screened-grid high frequency

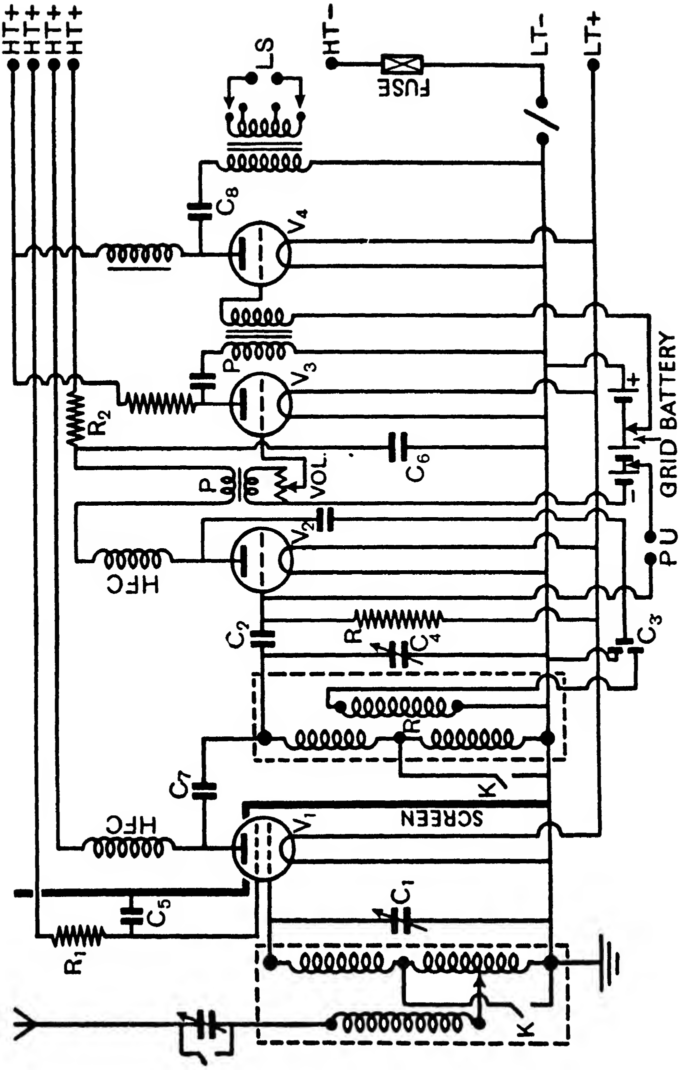

HT+
HT+
HT+
HT+
LS
HT-
FUSE
LT-
LT+
C8
V4
P
V3
R2
C6
VOL.
P
GRID BATTERY
V2
HFC
PU
C2
R
C4
C3
R
C7
K
SCREEN
HFC
V1
C5
C1
R1
K

Fig. 199.

amplifier V_1, a triode detector V_2, as usual, and a pentode V_3 in the last or output stage. We have indicated a special aerial tuning coil known as the DBA, but this can be any of those previously given: and of course a low frequency triode amplifying valve can be inserted between the detector and the pentode on the lines of preceding circuits, if desired. It will be noted that choke coupling is used between V_1 and V_2, and transformer coupling between V_2

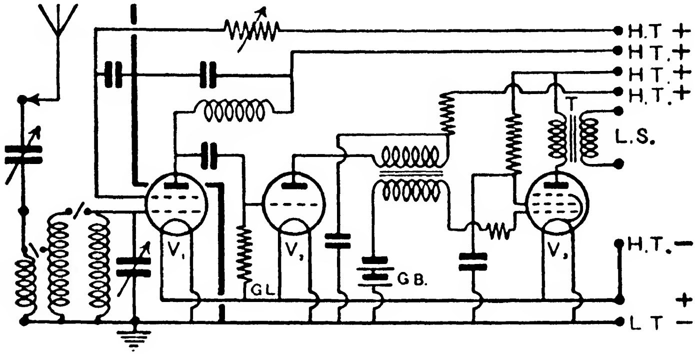


Fig. 200.

and V_3. Note that a pentode output transformer T is used with the loud speaker. "Screening" should be adopted with this circuit just as in Fig. 198. Incidentally, this circuit makes a satisfactory "portable."

A circuit employing a variable-mu screened-grid high frequency amplifier, followed by a triode detector, this being followed by a pentode in the output stage, is shown in Fig. 201, and from the details given in preceding circuits and in preceding pages you should have no difficulty in following out the circuit, its construction, and action.

Variable bias is obtained on the high frequency valve by means of a 50,000 ohm potentiometer P placed across the poles of the grid biasing battery. When the switch S is closed the three contacts are joined, the set is "switched on," and at the same time the grid battery is brought

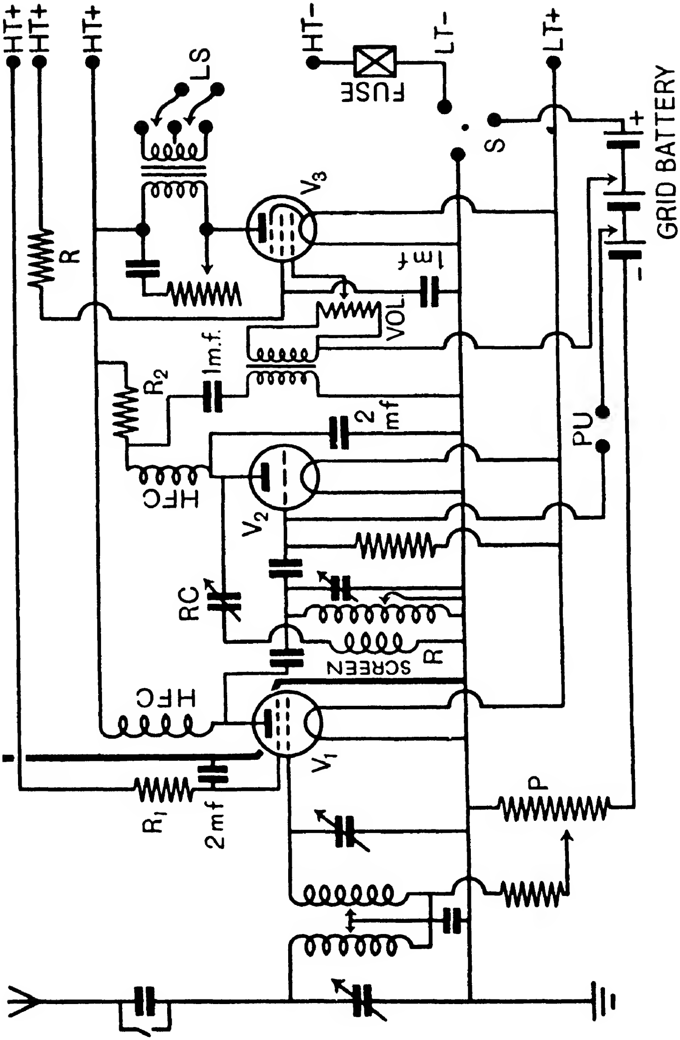

HT+
HT+
HT+
LS
HT-
FUSE
LT-
LT+
S
GRID BATTERY
+
-
V3
R
1 mf
VOL.
R2
1m.f.
2 mf
PU
HFC
V2
RC
SCREEN
R
HFC
V1
R1
2mf
P

Fig. 201.

into circuit: opening S not only disconnects the set but disconnects P and the grid battery. This is essential for the reason already given (page 235). The potential of the grid of V_1 is varied by varying the contact on.

In this circuit band-pass tuning is employed by using a band-pass unit in the aerial circuit as shown on the left of the figure. Tuned grid coupling is used between V_1 and V_2 and transformer coupling between V_2 and V_3. The loud speaker is transformer fed and a tone corrector is also inserted. Note again the decoupling.

A very powerful four valve circuit using a variable-mu valve in the first stage, followed by a detector, a low frequency amplifier, and a pentode in the output stage is shown in Fig. 202. Band-pass tuning is employed on the aerial side, tuned grid is used with the detector, resistance capacity coupling is employed between the detector and the low frequency amplifier, and transformer coupling between this valve and the pentode. The loud speaker is choke fed. The condenser values are C_1 ·0005, C_2 ·0005, C_3 ·0002, C_4 ·0003, C_5 ·005-·0001, C_6 ·0002, C_7 ·0005, C_8 1. The resistance values are R_1 80,000 ohms and P 50,000 ohms. Other values are as in preceding circuits. The arrangement and action of the circuit will be clear from details already given.

A circuit employing Class B amplification is shown in Fig. 202 (*a*). It is a three valve circuit consisting of a detector, a driver valve, and a Class B output valve. Little need be said about the circuit in view of the details already given. The aerial-tuning and detector connections are practically the same as those given in Fig. 197, save that in building it up we changed the coupling between V_1 and V_2 of that circuit from resistance-capacity to transformer. A Varley Class B output choke Y is used: this has three output ratios, viz. 1·5 : 1, 2 : 1, and 2·5 : 1, so that practically any speaker can be matched with the valve. The driver transformer X is a Varley (ratio 1·5 : 1). A tone corrector can be inserted where indicated, if desired:

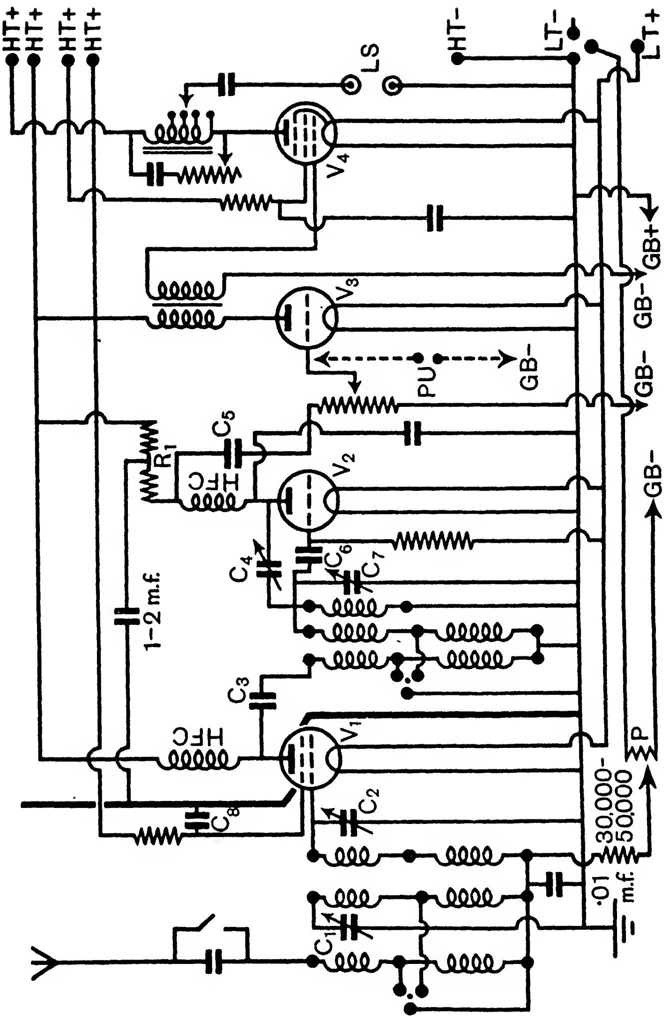

HT+
HT+
HT+
HT+
HT-
LT-
LT+
LS
V4
V3
V2
V1
GB+
GB-
GB-
GB-
GB-
GB-
PU
C5
R1
HFC
C4
C6
C7
1-2 m.f.
C3
HFC
C8
C2
C1
·01 m.f.
30,000-
50,000
P

Fig. 202.

the usual resistance can be used for this, but the condenser capacity should be ·01-·04 microfarad—larger than usual, owing to the lower impedance of driver transformers.

Owing to the importance of this method of amplification to the owners of battery receivers, we are going a step further and giving a few details of a commercial receiver employing the method. Fig. 202 (*b*) gives the

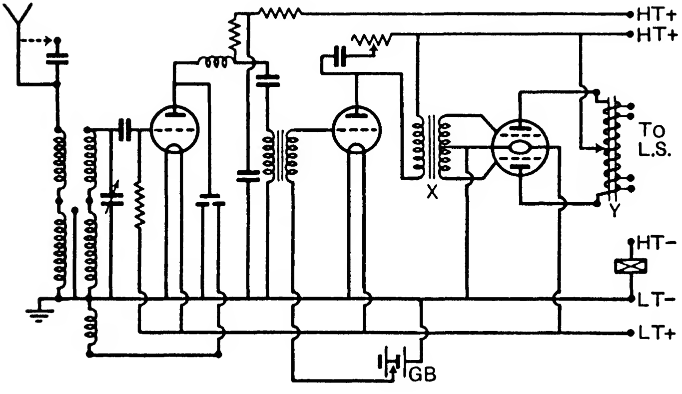


Fig. 202 (*a*).

circuit of the four valve Class B battery receiver manufactured by Messrs. Cossor who, as already mentioned, were the first to place the Class B valve on the market in this country. This gives added interest to the receiver.

The four valves used are (1) the new short base variable-mu screened-grid H.F. amplifier 220VS: this valve has a high impedance, a very low plate-grid capacity, a low high tension consumption, takes a filament current of ·2 ampere at 2 volts, gives a big amplification, and its grid bias can be controlled by a 9 volt battery only; (2) a detector of the 210HL type which also gives marked amplification; (3) a driver of the type 215P—a power valve with an amplification factor of 9; and (4) the Class B output valve

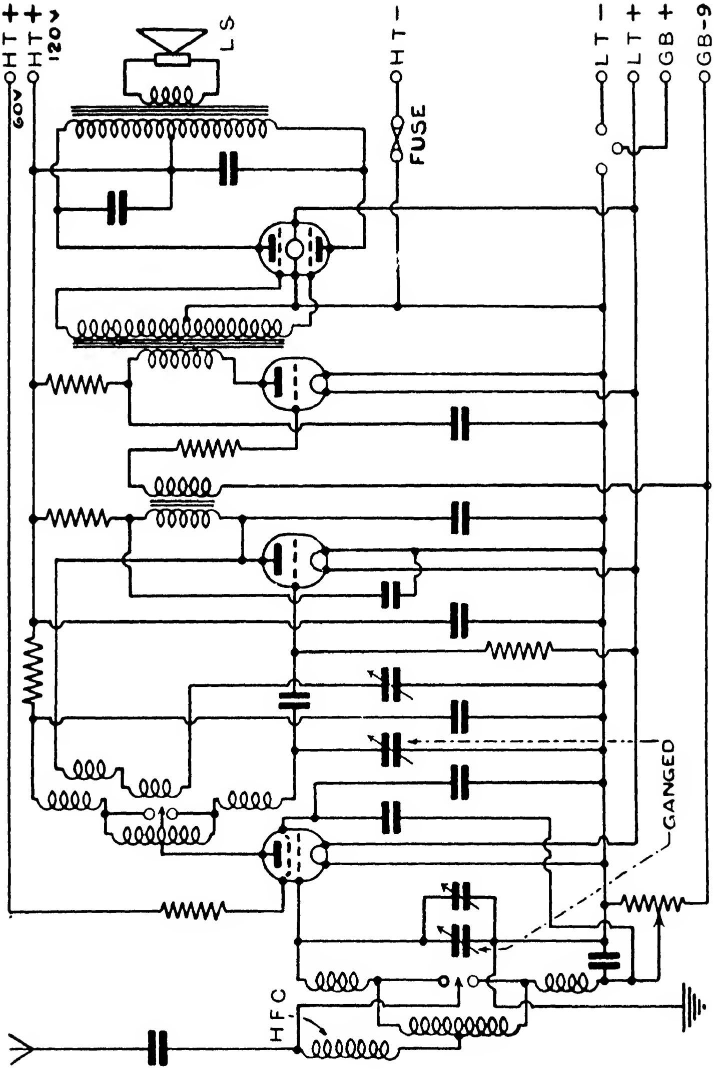


Fig. 202 (b).

220B: this valve is similar to the 240B valve already mentioned, but it takes a lower filament current (·2 as against ·4) and gives a smaller output than the 240B.

The aerial coil contains a small H.F. choke to eliminate any "break through" on long waves. All the couplings, etc., will be understood from the figure and from what has already been explained. The output transformer is attached direct to the loud speaker (which is of the permanent magnet moving coil type), both halves of the primary having a small condenser of ·005 m.f. capacity across them. We have emphasised the importance of "de-coupling" on several occasions: this is effectively carried out here as a glance at the diagram will show.

The controls are (*a*) a combined on-off switch and volume control, the latter varying the bias on the variable-mu valve; (*b*) a reaction control; (*c*) a tuning control—a single knob, but carrying a concentric knob for adjusting the "trimmer" when necessary; and (*c*) a wave change switch for long and medium waves. Arrangements for the reproduction of gramophone records are also incorporated. The circuit embodies practically all the features dealt with in preceding pages which lead to efficiency.

Volume is remarkably good: in listening to it, it is a little difficult at first to realise that it is only a four valve battery set draining the H.T. battery even less than an ordinary set would drain it. "Station getting" is very good: even on the very low wave band, stations came in at Cambridge of sufficient volume to be of real entertainment value. Selectivity too is good and tonal qualities excellent—a due proportion of high and low without bass-boom or unpleasant resonance. The receiver is one to be strongly recommended: it "speaks volumes" for Class B and Cossor modern circuit design.

11. Building from a Kit of Parts.

We have emphasised the importance of actual *construction*, for such work is not only interesting in itself but it results in an intelligent grasp of principles, and leads on to further experiment and improvements.

You should now be able to understand the various circuits which appear regularly in the Wireless journals, and should be in a position to set about the construction of a wireless receiver yourself. In doing this your best plan is perhaps first to put together a "Kit of Parts," using the matched components supplied by the makers and acquiring skill in working from the diagrams supplied.

To give you an idea of the possibilities of these "Kits" it will be best to take an actual example. There are many to be had—Cossor Melody Maker, Osram Music Magnet,

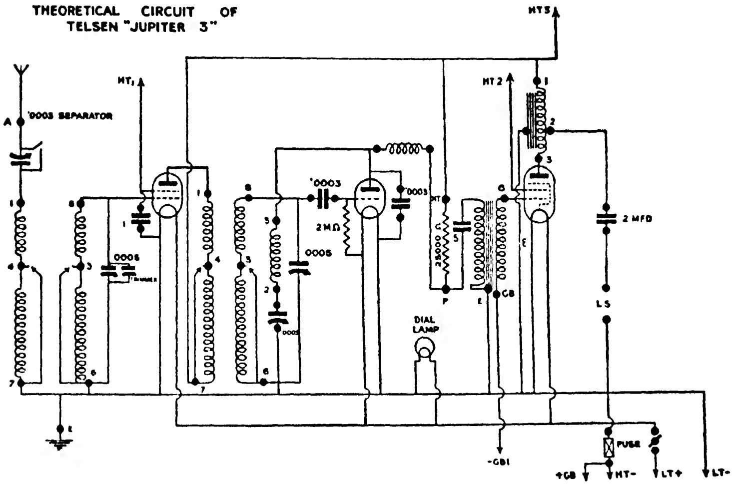


Fig. 203.

Sky-scraper, Telsen Jupiter and Super-Four, etc.—all reliable. We will take the "Jupiter" which is simple for a first "build-up," the wiring being all on the base and easy to follow: moreover it is modern, and its performance good and pleasing—for a straight three valver it is *exceptionally* good.

The circuit consists of a screened-grid high frequency amplifier, a detector, and a pentode. Two matched screened coils are used in the aerial circuit and in the

coupling between the screened grid and detector: a 10 : 1 low frequency transformer coupling unit is used between the detector and pentode. The speaker is fed by a tapped choke and 2 mf. condenser. The tuning condensers are ganged so that the two are operated by one knob, and a small trimmer condenser in the aerial tuning circuit is included. Reaction is provided and is capacity controlled. Wave length changing (medium or long) is done by a substantial switch operating on both tuners simultaneously. An aerial condenser (separator) is provided to still further increase the selectivity when necessary. It will thus be seen that the circuit embodies many of the special features we have dealt with in preceding pages.

For a straight three, the performance is remarkably good. In Cambridge over thirty stations were received at good strength. Selectivity is good, particularly on the medium waves. Mühlacker was received quite free from London at a distance of twelve miles from Brookmans Park.

A circuit diagram is given in Fig. 203, and you will be able to follow it out from the details given in previous pages and preceding circuits. The coils in the aerial and first coupling circuit are those shown in Fig. 68: they are fitted with cam operated rotary switches for wave changing (operated simultaneously) and are covered by aluminium screening cans. The tuning condensers C_1 and C_2 are drum driven ganged condensers operated by one knob: mounted on the same spindle is a control giving a separate movement of about 10° to the fixed vanes of one condenser, if required. The dial is graduated in wave lengths. The second coupling unit is a filter fed transformer (10 : 1) which gives a marked amplified input to the pentode.

A more ambitious constructional set is the "Super-Four," which is really an extension of the preceding. This has an all-metal chassis which, combined with the "canned" components, ensures perfect screening. The four valves are two screened grids, a detector and a pentode. The aerial is loose-coupled to the tuned grid of the first valve, transformer coupling is then used, and the excellent Telsen 10 : 1 coupling unit is again employed between the detector

and pentode: the pentode output is the same as in the preceding receiver. The triple matched coils (screened) and triple gang-condensers (screened) enable the tuning to be operated by one panel control, the other " controls " being an on-off switch, a reaction, a wave change, and a selectivity control. De-coupling is extensively employed

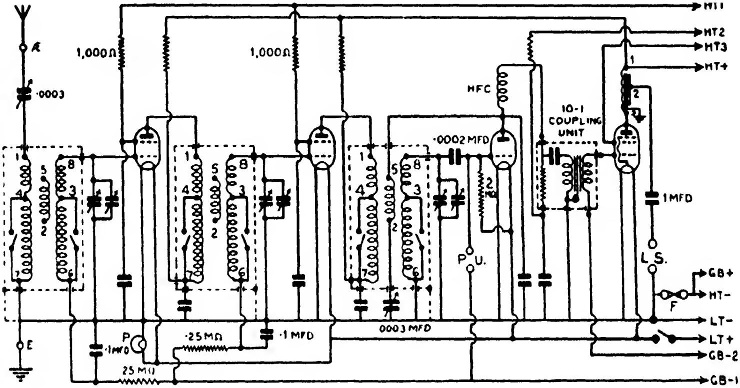


Fig. 204.

—a marked feature of the receiver. Arrangements for the reproduction of records are incorporated. The circuit is shown in Fig. 204 and it will be readily understood from the details given. As a straight-four-valve battery set which you can readily build this Super-Four Kit can be strongly recommended: its " station getting," selectivity, and output are really good—the best of this type of set we have come across: it is a set well worth building and possessing, and the knowledge you will gain by building it will prove invaluable.

12. All-Mains Receivers.

As already mentioned many receivers—perhaps most—are run off the mains, thus dispensing with batteries, either high tension or low tension or both. It was also stated that if the supply was alternating current it must be

turned into direct current for the H.T. plate supply, and, with both alternating and direct current supplies, the voltage must be reduced to the values required for the plates and filaments of the valves: further, smoothing devices—consisting of condensers and resistances—are necessary.

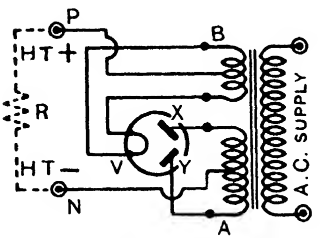


Fig. 205.

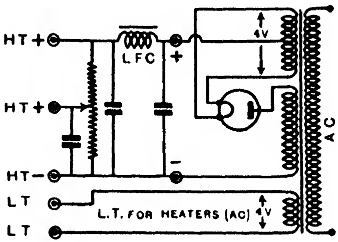


Fig. 206.

In the case of A.C., step-down transformers are used for the voltage cut-down, and diode valves are invariably used to rectify for the high tension supply.

In Fig. 205, imagine A and B to be two separate secondary windings of a transformer through the primary of which the A.C. supply is passing. V is a diode valve with two plates X and Y. These plates are joined to the ends of A and the filament is joined to the ends of B. The two secondary coils are centre tapped, the taps being joined to the terminals P and N shown.

Now in Chapter VIII. we saw that current flows through a diode when the plate is positive but not when it is negative. In Fig. 205 for every instant that one end of a secondary winding is positive the other end is negative, and therefore one plate of the valve is positive when the other is negative. In consequence there is always one plate acting to cause current to flow through the valve from plate to filament. As the centre tap has a potential half way between the two ends, it is always negative with respect to the positive end. Thus there is always a flow from one of the plates to the filament, thence to the

centre tap, to P, through the circuit R to N, to the centre tap, and to a plate. Clearly, then, P is our H.T. + and N our H.T. – for the high tension applied to the receiver. The number of secondary turns is so arranged that the voltage is stepped down to the correct amount for the valves. Remember that the centre tap on the secondary coil *joined to the filament* corresponds to the *positive* of the H.T. battery.

The above is called a **full-wave rectifier** because owing to the *two* plates acting as it were alternately both halves of the wave are made use of. There are **half wave rectifiers** where only one valve plate is used (Fig. 206): you should be able to think this out for yourself. We have shown the smoothing arrangements and voltage tapping in this figure.

Incidentally a *metal rectifier* consists of dissimilar metals in contact—in one form copper plates coated on one side with copper oxide and interleaved with lead plates: current only flows in the direction oxide to copper (see Fig. 209, *a*).

To illustrate an all-mains (A.C.) receiver we will take a simple three valver which shows the essential parts (Fig. 207). You will best grasp the idea from this very simple example.

All the valves are triodes, and consist of a high frequency amplifier V_1 followed by a detector V_2 and a low frequency amplifier V_3. Transformer coupling is used between V_1 and V_3 and between V_2 and V_3. The aerial tuning consists of the usual tapped plug-in coil L_1 and variable condenser C_1, the latter being ·0005 microfarad capacity.

The high frequency transformer coupling V_1 and V_2 is a form of Lewcos coil with six terminals which is put on the market for this purpose as well as for aerial tuning purposes. The six contacts are numbered 1 to 6. The centre tap, No. 4, of the primary goes to the high tension positive. One end, No. 5, of the primary goes to the plate of V_1 and the other end, No. 3, goes to the neutralising condenser C_5 and thence to the grid of the high frequency valve. The secondary coil of the transformer has the usual tuning condenser C_3 of capacity ·0005 microfarad across it: one end, No. 1, goes to the grid of the detector V_2: the other end, No. 2, goes to a terminal of the grid

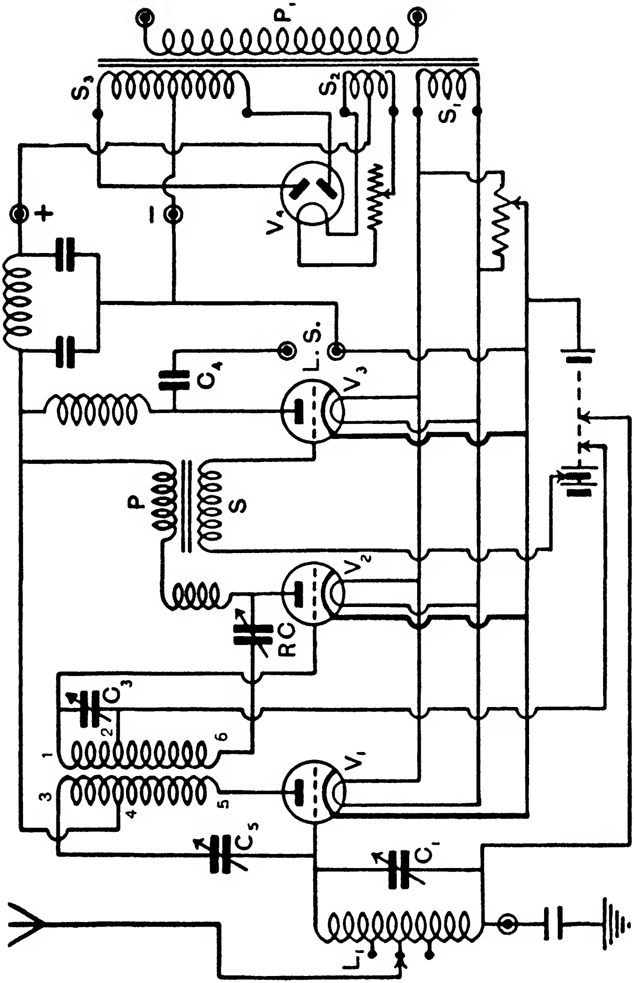


Fig. 207.

battery. The coil between 2 and 6 is the reaction coil: it goes *via* the reaction condenser RC (·0001 microfarad) to the plate of the detector.

The low frequency transformer coupling the detector V_2 to the low frequency amplifier V_3 is the usual type. An output choke and condenser C_4 (2 microfarads) are arranged as shown.

It will be noted that we are using anode bend rectification with the detector valve V_2 (not grid leak), and the connection on the grid battery from No. 2 of the high frequency transformer must be such as will give the required anode bend bias.

We come now to the battery eliminator on the right of Fig. 207. The power transformer on the right has a primary coil P_1, which is joined to the A.C. house supply and three separate secondary windings S_1, S_2, S_3: the voltage of the mains is therefore changed to three separate voltages on these secondaries, the values depending on the dimensions.

S_1 is generally a winding which delivers 4 or 6 volts, and it supplies alternating current to the heaters of the valves.

S_3 and S_2 are each centre tapped. V_4 is a rectifying valve consisting of a filament and two plates, one on each side of the filament. The ends of the smaller winding S_2 go to the filament, which is therefore heated by current induced in S_2. The ends of S_3 go to the plates. The centre tap on S_2 becomes the high tension positive connection, and the centre tap on S_3 becomes the high tension negative connection. We therefore use these points just as we do the high tension positive pole and high tension negative pole of the usual high tension battery.

This high tension (direct current) supply is, however, first passed through a "smoothing" arrangement consisting of a choke and two condensers, and the windings are such that finally a smooth direct current at, say 120 volts, is supplied to the plates of the valves.

If the supply is direct current, then, as already indicated, the voltage is cut down to the requisite amount for the valves by resistances, smoothing arrangements being

again used as in the preceding case. A device for the high tension supply is indicated in principle in Fig. 208. The largest voltage value is controlled by the resistance R_1 of 5,000 ohms and smaller voltages by tapping R_2 and R_3 each of 50,000 ohms. Chokes and condensers are included as shown, the condensers C_1 being of 2 microfarads capacity and C_2 of 4 microfarads. The filament supply can also be dealt with if desired. It is only on bad mains that the two high frequency chokes are really necessary.

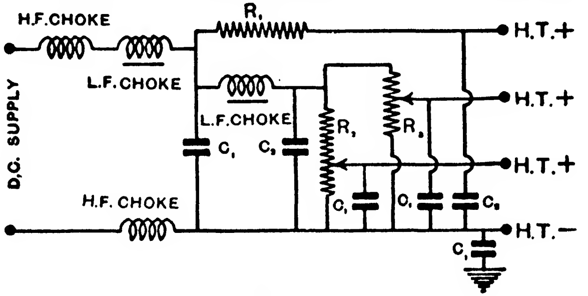


Fig. 208.

13. Fitting a Gramophone Pick-up.

In one or two of the preceding circuit diagrams we have placed the letters PU in a path leading from the grid biasing battery to the grid of a low frequency amplifying valve, or in the path leading to the grid of a detector valve: this is to indicate that a gramophone pick-up may be inserted " here-abouts."

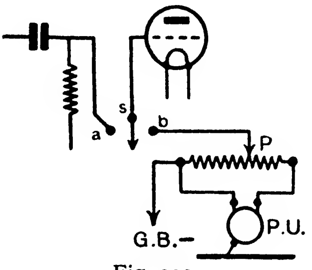


Fig. 209.

The method of actually connecting the pick-up, say, to the grid of a detector valve is shown in Fig. 209. The wire from the grid of the detector to the grid condenser (leak) is removed from the condenser and joined to the

centre terminal of the switch S. Terminal *a* is joined to the grid condenser, and terminal *b* to the slider of a volume control potentiometer P. One end of the control is joined to one lead from the pick-up and the other end of the control is joined to G.B. — and the other pick-up lead.

If the receiver has two low frequency stages after the detector the volume may be too loud if the pick-up is joined to the detector grid: in that case we join to the first low frequency valve. In the figure turning the switch to *a* receives radio, turning to *b* gives the record reproduction.

The pick-up consists essentially of a coil between the poles of a magnet, the coil being connected to the gramophone needle and moving with it.

The pick-up and its needle, of course, replace the usual sound box and its needle on the record: the varying currents developed in the pick-up as the record rotates are amplified by the valves and the sound reproduced by the speaker in the usual way.

In the *radio-gramophone*, the wireless receiver and the gramophone are combined in one instrument. The best makes of these are "all electric," the mains driving the gramophone motor as well as supplying the receiver.

14. Using a Battery Eliminator or "Mains Unit."

We have referred to the metal rectifier. It uses several plates of two different materials—say copper plates coated on one side with copper oxide, the plates being interleaved with lead. Electrons diffuse from copper to oxide but not from oxide to copper. Thus an electronic current can flow only from copper to oxide and therefore a conventional current from oxide to copper: the device therefore *rectifies*. The construction is shown in Fig. 209 (*a*).

An *eliminator* or *mains unit* is a device for supplying current to a wireless receiver from the house electric supply, thus dispensing with batteries (see pages 160, 271). For use with A.C. mains they contain a rectifier usually of the metal type just mentioned, a transformer for changing the voltages to those required, together with chokes and

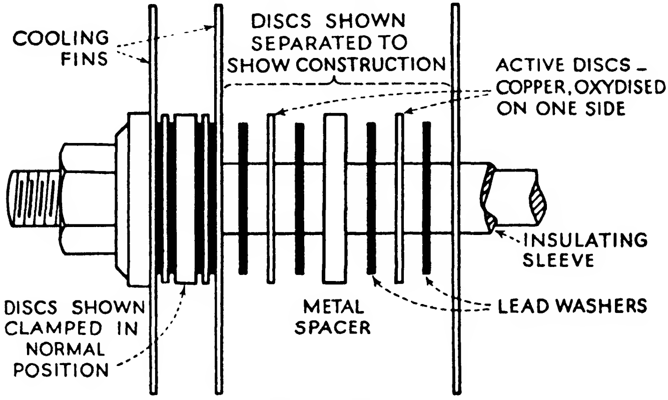


Fig. 209 (*a*).

condensers for smoothing the current as already explained. Units for use on D.C. can also be obtained.

Many listeners with favourite battery receivers hesitate to turn over to the mains, being under the impression that the conversion is complicated and technical, but this is not so. And in most cases the advantages gained by the change are considerable. Frequently no alteration in the circuit or valves is required, but better all-round results are obtained, disappointments caused by a failing H.T. battery disappear, running costs are considerably cut down, and that most important item—renewal of H.T. batteries—is avoided.

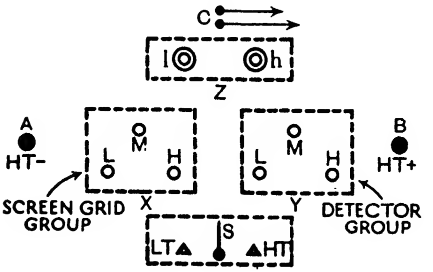


Fig. 209 (*b*).

To indicate exactly how simple the "change-over" is, we must consider a

definite example in illustration, and for that purpose we will take the *Regentone H.T. eliminator*. We have tested this unit thoroughly and it has proved highly efficient: its "smoothing" is excellent, it has seven different voltage tappings, back coupling is eliminated, it is silent in operation, and its steel outer case is earthed to avoid any "mishaps" with live parts. Now for the simplicity of conversion.

Fig. 209 (*b*) shows diagrammatically the "sockets," etc., on the top of the unit. The negative high tension lead of the set is plugged into A. The maximum positive high tension lead (we will suppose this to be 150 volts) is plugged into B. At X there is a group of three sockets into *one* of which the lead from the screening grid of the screened-grid valve (or valves) is plugged. The choice of three voltages is possible here, viz. M (Medium, 65 volts), H (High, 85 volts), and L (Low, 50 volts). At Y there is another group of three into *one* of which the high tension lead for the detector is plugged: three voltages are available here also. At Z there are two screwed sockets and a screw: if the screw is put into *h*, the full voltage the unit is rated at is supplied: if it is in *l* the output is about 25 per cent. less. Models can be had to suit various input and output voltages. The accumulator and grid bias are joined to the set in the usual way. The unit can also be obtained in a form which will charge the accumulator when the set is not in use. In this case leads come out of the cover at C and are joined to the accumulator, and a switch S is provided: when charging the switch is turned to L.T.: to work the set it is turned to H.T. Further models for use with Q.P.P. and Class B receivers are available.

15. On the Short Waves.

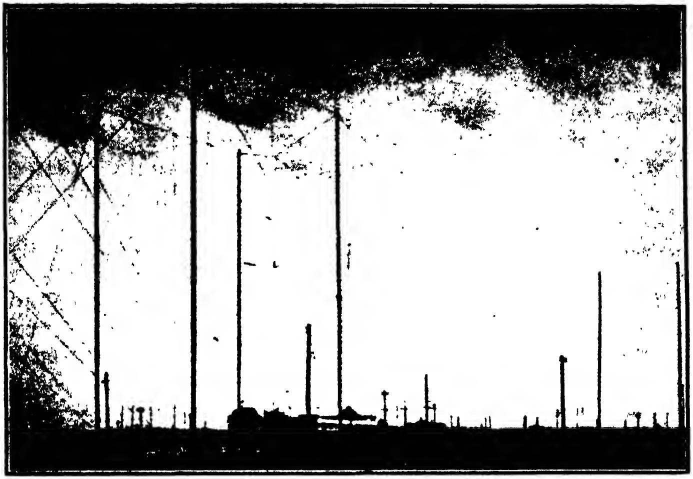
The medium broadcasting band of wave lengths—say 200-600 metres—represents a *frequency band* of from 1500 kilocycles (300,000 ÷ 200 = 1500) to 500 kilocycles, *i.e.* 1000 kilocycles only, and is literally packed with broadcasting stations (over 100) at 9 kilocycles separation: the aether hereabouts is conjested—not another station could be got in without causing interference.

There is, however, plenty of elbow-room in the aether if we transmit on short waves (high frequency), say from 12 to 150 or so metres. The frequencies corresponding to these are 25,000 and 2000 kilocycles respectively, a *band* of 23,000 kilocycles. A very large number of stations—over 2500—at 9 kilocycles station separation could therefore be accommodated here: moreover we could fit in many stations and allow a greater station separation than 9 kilocycles thus further reducing the possibility of interference between stations.

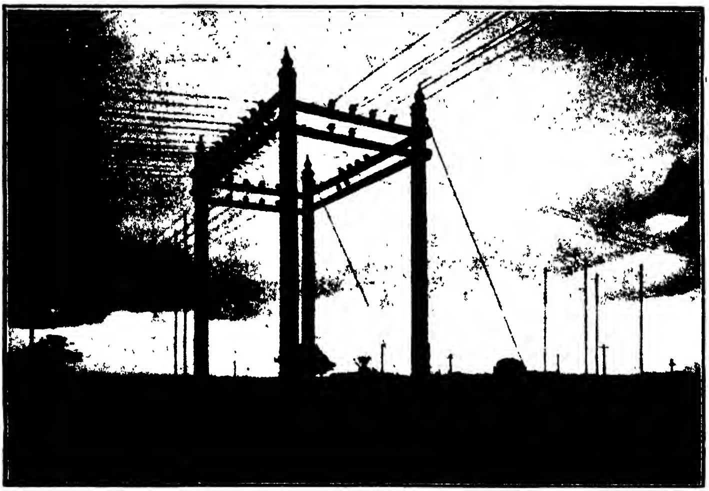
Again, short waves lend themselves particularly to long distance transmission and reception. As already indicated the ground waves are soon absorbed but the atmospheric or sky waves are mainly reflected by the Appleton layer, and it is partly owing to the greater height of this that they come down at a greater distance from the transmitter thus resulting in greater signalling distances (pages 140-141). As you know, it is *just possible on favourable nights during the darker months to receive some of the more powerful medium wave broadcasting stations* of the United States and South America (3000-4000 miles distant), but this is about the maximum distance even when conditions are at their best: *on short waves, however, these countries are within receiving range practically the whole time.* Short wave transmissions from so far away as Sydney in Australia are, for example, regularly received in this country. And almost every country in the world is now sending on short waves as well as on medium and long. Amateur (experimental) work is also done on short waves.

As a matter of fact, as we have seen, *all* long distance transmission is really due to reflections of the sky waves by the Heaviside and Appleton layers. The actual effects of these layers, however, depend on many factors, viz. the wave lengths, the time of day and night, the seasons; and they also vary from year to year.

Consider first the question of wave lengths. The ordinary broadcast waves are reflected by the Heaviside layer, the short waves mainly pass through the Heaviside and are reflected by the Appleton layer, and still shorter



EMPIRE BROADCASTING STATION, DAVENTRY.
The West African Aerial Array with the Empire Station Building in the background.



EMPIRE BROADCASTING STATION, DAVENTRY.
One of the Feeder Line Termination Units.

waves (the *ultra-shorts*, say 3-10 metres—used in television) seem to pass through both. Again, in short wave reception it often happens that at one period of the 24 hours a certain wave length gives excellent results whilst at another period results with it are poor though a different wave may give excellent reception at this same period.

Further, the Appleton layer in particular (which mainly turns the short sky waves back) seems to alter its qualities from year to year, such alteration being associated with the variation in *sun spots*. Sun-spots follow eleven-year cycles: there was a maximum sun-spot period in 1928 followed by a decrease to a minimum in 1933, and then an increase which will culminate in a maximum sun-spot period again in 1939. In unison with this cycle the reflecting layer is changing and so is long distance short wave transmission and reception. *Short* wave reception grows better and better with increasing sun spot activity (long wave reception grows somewhat worse). It is possible that our knowledge of the reflecting layers and of the peculiarities of short wave transmission and reception will be considerably enlarged during the next few years and the 1939 epoch.

It may be mentioned that short wave transmitting has an economic advantage over long wave transmitting because much less transmitting power is required to produce signals of a given strength at a distant point than with long waves: this is because a much higher proportion of the energy is radiated from an oscillating circuit if the frequency is high (waves short). Further, short waves can be readily reflected and concentrated into a beam directed towards a particular receiving station instead of radiating the energy indiscriminately in all directions. Theoretically, of course, it is possible to concentrate aether waves of *any* length into " beams " by means of suitable reflectors, but the " dimensions " of such reflectors must be large compared with the wave length: hence it is possible to do so in practice with short waves but it is impracticable with long waves. This will be referred to again later.

To return to the broadcasts on short waves. Such transmitting from various countries is classified into four main bands (sometimes six) known as the 1·5 megacycle, the 3·5 megacycle, the 7 megacycle, and the 14 megacycle bands (1 megacycle = 1000 kilocycles = 1,000,000 cycles). It used to be the custom, on account of the large frequency range to be covered, to use three or four different coils (generally of the plug-in type) for tuning receivers, and to change over from one coil to another for the different bands. This is still done in experimental work, but in modern commercial receivers the change from one band to another is usually accomplished by the simple rotation of a single switch knob just as is done in changing from the medium to the long wave band in an ordinary receiver. As an example, in one particular commercial receiver (long, medium, and short waves) the whole of the short wave bands from 1·5 megacycles (*i.e.* 200 metre wave) where the medium wave band ends to 23 megacycles (13 metre wave approximately) is covered, the change from one band to another being effected by the rotation of a knob.

The 1·5 and 3·5 megacycle bands include transmissions from many amateurs, the police including London and the Provinces, fishing trawlers, lightships, coast stations, other Service transmissions, and broadcast programmes from Lisbon, Rome, Quito, Copenhagen, etc. The 7 megacycle band (within the wave lengths 50 to about 29 metres) carries a large number of excellent transmissions including programmes from Madrid, Sydney, Philadelphia, Daventry Empires, Melbourne, Moscow, Pittsburg, Johannesburg, Chicago, Cincinnati, Montreal, etc. The 14 megacycle band is very prolific in what might be called "star" transmissions (within the wave lengths, say, 25 to about 13 metres), reception in most cases being very good in daylight: the band includes Daventry Empires, Boston, Vatican City, Winnipeg, Rabat Morocco, Wayne, Zeesen, and many other stations.

A receiver for short waves is the same in principle and much the same in construction as those already dealt with, the components being suitable, of course, for the higher

frequencies—shorter waves—employed, but space forbids us going into detail—and it is really not necessary in this book. It is, however, surprising what results can be obtained on a simple set, even a home made two or three valver. Fig. 209 (*c*), which gives the circuit of one we have used ourselves for some time with excellent results, will indicate this, and you should be able to understand it from the circuits already explained. Short wave coils can be purchased cheaply from several makers: for example Messrs. Wright and Weaire make a set of three which

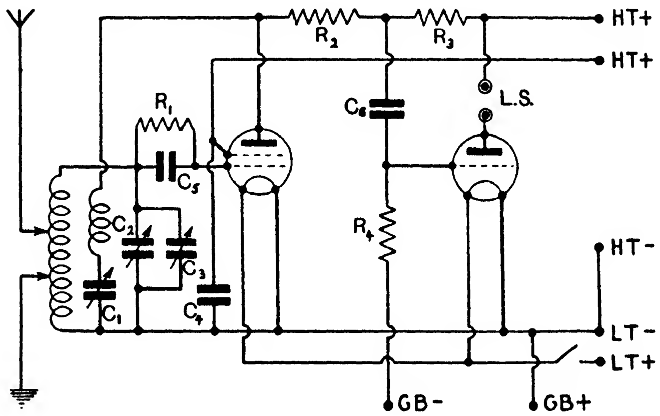


Fig. 209 (*c*).

covers all wave lengths between 12 and 175 metres. The values of the other components in the above circuit are as follows: C_1 = ·00015 mf.; C_2 = ·00015 mf.; C_3 = ·000015 mf.; C_4 = ·01 mf.; C_5 = ·0001 mf.; C_6 = ·01 mf.; R_1 = 2 megohms; R_2 = 10,000 – 15,000 ohms; R_3 = 50,000 ohms. Although simple sets of this type are quite satisfactory, if greater certainty of very long distance reception is required what is known as a " superhet " circuit may be employed: the principle of the superhet is dealt with in the next chapter.

If you already possess a favourite receiver for ordinary broadcasts (long and medium waves) you can purchase (or make) a very simple device to couple up to it so that it can also be used for short waves. This simple attachment need only be a single valve circuit—much the same as the single valve (detector) circuits described in Chapter X., but, of course, with tuners, etc. (coils and condensers) suitable for short waves. They usually take one of two forms referred to as *short wave adapters* and *short wave converters*. If arranged as an *adapter* it adapts the receiver to short wave tuning and may be used with any receiver. If arranged as a *converter* it really converts the receiver into a superhet and, as will be seen later, can therefore only be used with a receiver employing high frequency amplification.

For short wave reception the ordinary aerial may be used in many cases, but it is much better to use a special (shorter) short wave aerial: this is described in the next chapter.

Many commercial " all wave " receivers—long, medium, and short waves—are now on the market in which, as stated, the change from one band to another is accomplished by the mere turning of a knob.

Short wave wireless is used at the B.B.C. Empire Station at Daventry for *broadcasts* with the Dominions. The Empire is divided into six zones and, owing to its world-wide distribution and consequent " differences in times," transmissions must be sent out to the different zones at different times, so that some of the transmitters are on the aether practically throughout the whole day and night.

There are six transmitters, three being rated at 50 kilowatts input, two at 10, and one at 25—a total input of 195 kilowatt. The six stations can operate, however, on no less than 16 different wave lengths with separate call signs as follows (the wave lengths are given in metres):—

GSK	11·49	GSG	16·87	GSF	19·82	GSC	31·32
GST	13·92	GSP	19·60	GSE	25·29	GSB	31·55
GSJ	13·93	GSI	19·66	GSN	25·38	GSL	49·10
GSH	13·97	GSO	19·76	GSD	25·53	GSA	49·59

In all there are 23 aerial systems which can transmit in twelve different directions to the various zones, and by a switching arrangement any of the six transmitters can be connected to any of the 23 aerial systems. It is rarely found necessary to have more than three or four radiating at the same time. By a system of reflectors the signal can be concentrated and its strength intensified in any area where the reception is not up to standard. When a programme time coincides with a Regional or National transmission certain items are relayed and sent out on the Daventry transmitters: in fact all programmes, including those " bottled " for broadcasting during what to us is " night," go from London to Daventry.

Of course, these Empire broadcasts on short waves can be picked up in this country, and are regularly picked up in America and elsewhere.

The " beam " systems of *commercial* wireless communication with the " Dominions " also use short waves. The Government decided on the project in 1923, and the Marconi Company erected short wave stations to communicate with Canada, South Africa, Australia, and India, the short waves in each case being projected in the form of a beam to the desired receiving station by means of reflectors. The first to be erected were for communication with Canada, the sending station being at Bodmin and the receiving station at Bridgwater (the corresponding transmitting station in Canada was erected at Drummondville, 30 miles north-east of Montreal, and the receiving station at Yamachiche, north of Drummondville). The English stations are linked up by land lines to the G.P.O., London, and the Canadian stations by land lines to the central office in Montreal. Sending and receiving systems for the South African service were also arranged at Bodmin and Bridgwater respectively, whilst similar stations at Tetney, near Grimsby, and at Winthorpe, near Skegness, were arranged for the Australian and Indian services.

The aerial system for each service (*aerial array* it is called) consists of a number of vertical wires, somewhat

like a wire curtain, suspended from a steel cable attached to a row of masts. The reflecting system consists of a similar set of vertical wires suspended from another steel cable and arranged behind the aerial wires. The aerial system is on the side of the masts facing the distant station, and " faces," along a " great circle," the place to which it is desired to transmit. The vertical wires are energised by currents having suitable phase relations to cancel out the radiation in all but the required direction. Thus, by this aerial and reflecting device the " beam " is projected in the direction of the receiving station, thus reducing waste of energy and increasing signal strength; and similarly at the receiving station energy is also reflected on to the aerial, again increasing signal strength.

The wave length is varied at different times of the day and year according to the regions of light and darkness through which the waves have to travel: similarly in sending to Australia the waves are sometimes sent " east," sometimes " west," according to the time of day.

There are other beam stations, *e.g.* Dorchester, Somerton, etc. Portishead gives "world wide" service with ships on short waves and also uses long waves. Rugby is a super-power "world wide" station: it uses long waves but has a telephone service on shorts.

In ordinary broadcasting, a single programme from one studio is often " sent out " by several stations in different parts of the country. In such cases the current variations of the microphone in the studio are usually sent (after amplification) along land lines to the various stations where they are ultimately caused to modulate the carrier waves of these stations. Such " simultaneous broadcasts," however, also make use of the " radio relay system." One plan is to send out a programme on *short waves*, which is received by a special receiving system at another station and then broadcast on that station's ordinary carrier.

Incidentally, *ultra-short waves* (below 10 metres) are also used as " radio links " in ordinary telephone systems. A link using 5 metre waves is in use across the Channel.

CHAPTER XII.

VALVE TRANSMISSION. SUPER-HETERODYNE RECEIVERS. TELEVISION. TELE-CINEMATOGRAPHY. TELE-PHOTOGRAPHY.

In Chapter VI. we explained that many methods were in use in transmitting stations for the production of *continuous* oscillations and waves for wireless telegraphy and telephony—electric arcs, high frequency alternators, high frequency alternators in conjunction with frequency changing transformers—but that these were being largely superseded by methods employing valves. Now it is impossible in this book to describe in detail these modern and complicated methods, but we will explain how a valve can be arranged to maintain oscillations and waves.

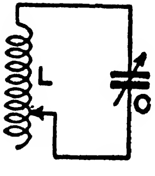


Fig. 210.

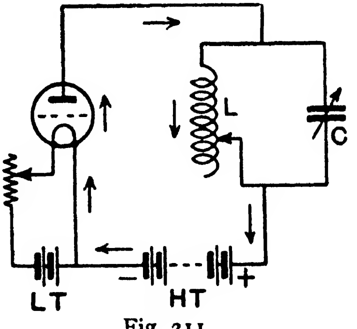


Fig. 211.

1. Using Valves for Transmitting.

You will remember from Chapter VI. that if we take an inductance L and a condenser C and form a closed circuit (Fig. 210), and if, somehow or other, we start electrons flowing in the circuit they will oscillate backwards and forwards, the condenser being charged first one way then

the other: if the resistance is small the electrons will have several swings before they pull up. Clearly for a practical circuit we must keep up the electrical oscillations in this LC circuit, *i.e.* keep the electrons on the " to and fro."

The next question that arises is how to start and "keep up" the oscillations of electrons in the LC circuit.

Look at Fig. 211. You will notice it is simply a valve circuit, only we have not yet done anything with the grid, and our CL closed circuit is in the plate circuit of the valve. As the filament is being heated by the low tension battery it will be giving off electrons, and a *steady* electronic plate current will be flowing from the negative pole of the high tension battery HT to the filament, through the valve from filament to plate, and from the plate through L to the positive pole of the high tension battery.

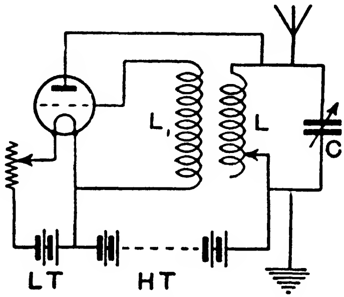


Fig. 212.

Notice that this is a *steady plate current going through* L, whereas what we want are *oscillations* in the LC circuit. We must evidently break this up somehow or other so that it becomes a varying current instead of flowing steadily on, and we can do this by bringing the grid into action, *i.e.* by putting the grid, so to speak, on " point-duty " to regulate the traffic of electrons in the valve between the filament and the plate.

Now let us take another coil L_1, join it to the grid and the filament, push it up against L (Fig. 212), and consider what happens. Just for an instant the current in L acts inductively on L_1 and starts a momentary current in it: this current varies the potential of the grid, and the grid starts its point-duty, *i.e.* this change in the potential of the grid varies the plate current. This sudden change in the previous steady plate current starts up oscillations in

the LC circuit—just what we want. Then the oscillations in LC, acting inductively on L_1, produce oscillations in L_1 in unison or in step with them. These latter now vary the potential of the grid in unison or in step with the LC oscillations, and this again produces changes in the plate current in unison or in step with the LC oscillations.

Evidently the combined result of all these actions and reactions which are in step—the closed LC circuit, the grid circuit, and the plate circuit,—is to build up strong oscillations in the LC circuit, which is exactly what we require. Incidentally, for rigid scientific accuracy there are one or two things about this which we should mention, but we will not bother you with them, for they do not interfere with the broad idea we are wanting you to get hold of.

Now before going further you should carefully think over again all the above steps in the creation of strong oscillations in our oscillating circuit LC—how we began with a steady current in L in the plate circuit of the valve, how we momentarily altered the potential of the grid by putting L_1 in the circuit, how this produced a change in the plate current which was all that was necessary to start oscillations in LC, how these, by induction, produced corresponding ones in L_1, thereby varying the grid potential in step with them, how this again produced corresponding changes —again in step—in the plate current, and how in this way strong oscillations were built up in LC. In practice, the initial *starting* of the oscillations in the LC circuit of the valve is usually effected by merely switching on the high tension supply to the circuit.

The next step is evidently to bring a transmitting aerial into action. This can be done by joining up an aerial and earth direct to our oscillating circuit as shown in Fig. 212, or by inductively coupling an aerial to our coil L: in this case, of course, oscillations are produced in the aerial by induction from L.

It only remains now to join up a microphone so that the variations in the microphone current produced by the voice or music vary the *strength* of the oscillations in LC, thus

modulating the aether waves, *i.e.* producing a complicated wave such as was shown in Fig. 106, in which the ***strength*** rises and falls in a way depending on the words or music. There are several ways in which a microphone can be joined up to produce these necessary rises and falls in the strength of the oscillations, and perhaps the simplest for our purpose is shown in Fig. 213.

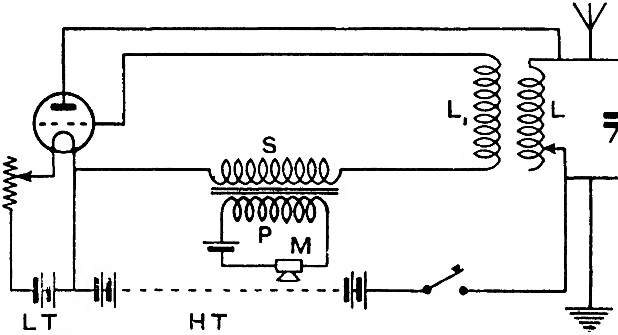
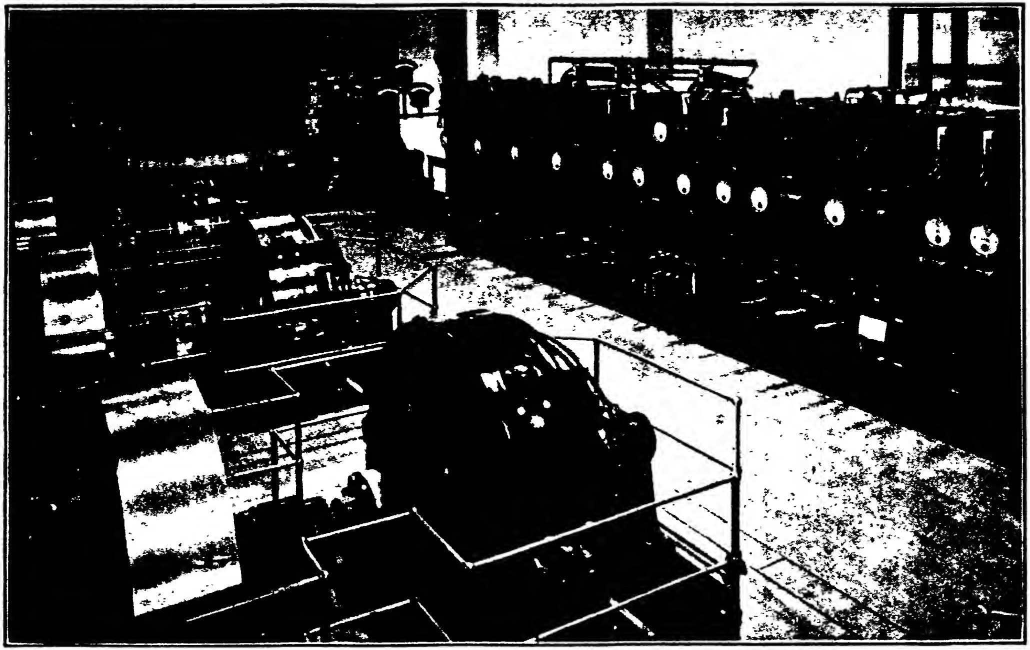


Fig. 213. Modulation applied to grid of oscillator valve.

Here the secondary S of the microphone is put into the grid circuit as well as L_1. When we speak, say, into the microphone we get current induced in S varying according to the words spoken: these vary the potential of the grid accordingly, which again varies the plate current, the strength of the oscillations in LC, and the waves.

We stated that we wished the microphone variations produced by the voice to be as big as possible, and you can easily understand how a valve can be used. Thus the microphone variations could be applied to the grid of a valve and the magnified and corresponding variations in the plate circuit of that valve could then be used for modulation. Fig. 214 shows a simple circuit. Both valves get their plate currents through a "speech choke." When the microphone is not in use the valves are (by grid bias) adjusted, to take equal plate currents and the oscillator sets up its constant oscillations. When M is in use, then



THE B.B.C. NORTH REGIONAL TRANSMITTING STATION.

Part of the Power House showing the main switchboard and three of the four D.C. generators

(owing to the high impedance of the speech choke) the plate voltage of the oscillator as well as of the modulator varies in unison with the M variations, and so does the inductive effects on the aerial: thus the aerial current is modulated.

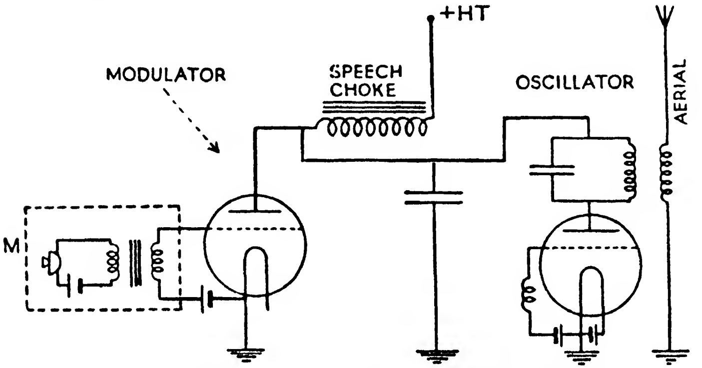


Fig. 214. Modulation applied to plate of oscillator.

2. A Few Facts about the Transmitting Station.

For transmission large valves (some 10 ft. high—water-cooled anodes) are used. Thus *ten kilowatt valves* with water-cooled anodes have been in use for some time, and 500 *kilowatt types* are also used. In high power transmitting sets it is, of course, necessary to use several valves: these are in series, or parallel, or series-parallel according to circumstances.

For transmission over long distances—hundreds or thousands of miles—the voltage applied to the plates or anodes must be high in order to get sufficient energy into the transmitting aerial—it may be many thousand volts (say 12,000). This must of course be direct current. In some cases high voltage direct current generators driven by oil engines (running on heavy oil) are used. In other cases alternating current is employed either from the mains or from alternators, the alternating current being of course rectified for supply to the anodes of the valves. Diode valves are very suitable as rectifiers, and the principle

of the arrangement is shown in Fig, 214 (*a*). The A.C. supply (single phase) from the alternator at the top of the figure is stepped up to the right voltage by the transformer, rectified by the two diode valves, smoothed by the condenser, and passed on as a steady D.C. supply to the anodes of the valves (compare Fig. 205, page 270). Neon or other gas-filled tubes and mercury vapour arc rectifiers are also in use. Polyphase current is used in some stations instead of single phase for the main supply. To avoid the trouble caused by the burning out of the rectifier valves, some stations use the A.C. supply on A.C. motors to drive D.C. generators to provide the plate supply. The B.B.C., for example, uses motor generators, and so does Rugby where the D.C. generators can give 18,000 volts if necessary.

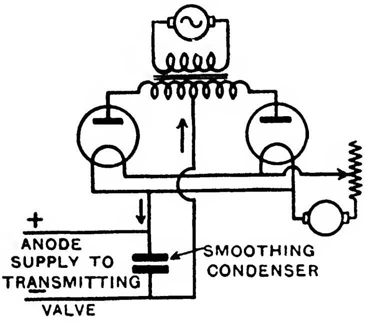


Fig. 214 (*a*).

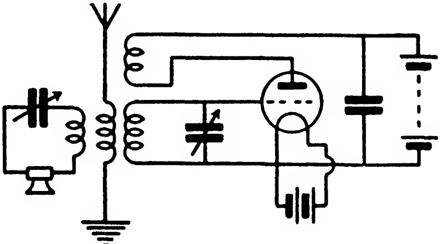


Fig. 214 (*b*).

The supply to the heaters (or filaments) may be from accumulators or D.C. generators. For high power sets the filaments are often heated from *step-down* transformers, supplied by the alternator used for the plate supply. Of course the heating current may be either D.C. or A.C.

The microphone used for "modulating" the output of the oscillating valves may be in various positions. In Fig. 213 it was arranged to modulate the grid voltage: in Fig. 214 (*b*) modulation is applied to the aerial by coupling: in Figs. 214, 214 (*c*) modulation is applied to the anode voltage. Of course these figures are considerably simplified to show general principles. Bear in mind, too, that the microphone variations are amplified by other valves (Fig. 214) before being applied to the oscillator. Remember, too, that the studio microphone may be some distance from the transmitting set. Modulation of plate voltage is the method usually employed in broadcasting.

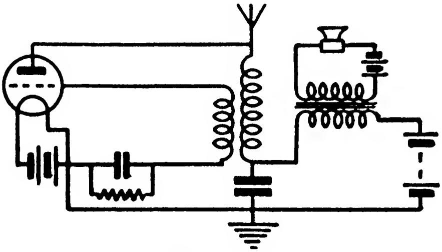


Fig. 214 (*c*).

Transmitting aerials (and masts) are also on a large scale, as is to be expected, and as will be seen from the figures on pages 129 and 279. For small stations tubular metal masts built in sections are usually employed. Wooden lattice masts supported by guys, and rigid steel towers are also used. Masts are sometimes insulated, sometimes earthed. In the Rugby station the steel lattice masts are insulated, Norwegian granite being used for the bulky portion of the insulating feet and porcelain "cheeses" for the part requiring great electrical strength. Masts may be 500 feet or more in height.

The earthing arrangement in large stations is a matter of vital importance. In practice, earth wires are invariably run radially from the station over the whole of the "wireless area," and frequently a little beyond it. Sometimes the

wires are totally buried in the ground: sometimes they are supported several feet above the ground and connected to earth plates at the far ends: sometimes again they are not earthed at all, in which case they form the lower portion of a balanced aerial system (frequently referred to as an *aerial screen*).

The method of generating the high frequency aerial oscillations in a modern station is briefly this:—A small oscillator (master oscillator) generates a small high frequency voltage of the required frequency. This is applied to the grid of a valve having its anode circuit (inductance and condenser) tuned to the same frequency. The magnified high frequency plate voltage here is passed to another valve for further magnification, and so on for several stages. The final stage would employ a valve (or valves) with 12,000-20,000 volts on the plates. The final stage is loose coupled to the aerial.

The routine of "starting up" a station depends on the equipment and switchboard arrangements; in some stations everything is practically managed from the switchboard—in others it is a more lengthy business. In one of our Regionals the main power is first switched on, the water pumps started running, and then the Diesel engines are set going: low tension, grid bias, and high tension are then switched on, in the order given, for the first stages: then come the battery supplies for the master oscillator, and finally the 10,000 or 12,000 volt generations are started running and the station is "on the aether."

3. The Super-heterodyne Receiver.

The consideration of this type of receiver has been purposely held over until we had explained to you the principle of a valve circuit working as a producer (more exact-maintainer) of oscillations for transmission.

Broadcasting conditions are becoming more and more difficult to cope with. Greater power is being used in transmitting stations: stations are rapidly increasing in number: and the demand for selectivity in a receiver,

apart altogether from excellence in reproduction is becoming more and more pronounced. And the superhet has been specially designed to combat the intolerable nuisance of "overlapping"—the creeping-in of unwanted stations.

In dealing with high frequency amplification in previous pages we showed that, largely owing to unwanted but unavoidable capacities, the difficulties encountered increase tremendously as the frequency is increased. In the superhet principle, however, the incoming high frequency is

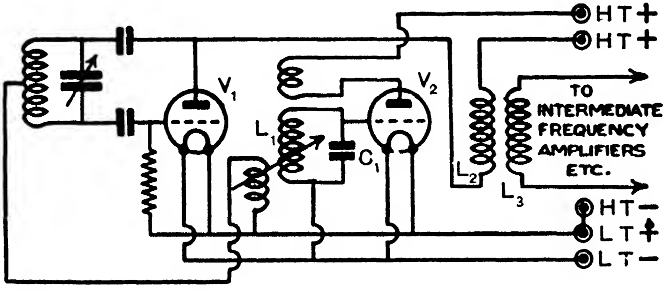


Fig. 215.

first reduced to a high frequency of more normal value, and then the usual high frequency amplifier is brought into action to deal effectively with the signal at this reduced frequency: after this come the detector and low frequency amplifiers in the usual way.

The frequency change is brought about in a similar way to that indicated for the heterodyne reception of the continuous waves in telegraphy (Chapter VI.). You saw there that the incoming oscillations were combined with a local oscillation thus producing a resultant oscillation whose frequency was really the difference between the signal frequency and the local frequency: it was arranged in that case that the "difference frequency" was a note frequency, *i.e.* such as to produce a sound in the telephones. In the present case, however, the incoming high frequency oscillation is combined with a local oscillation, but the

resultant is still high frequency (referred to as "intermediate ") which can be effectively "detected" and treated in the usual way. The local oscillation is produced by a valve oscillator circuit, and you should have no difficulty in understanding how this can be brought about from the details we have already given you.

The general principle, as far as the first two valves is concerned, is indicated in Fig. 215. V_2 with its associated inductance and condenser circuit L_1C_1 constitute the local oscillator, the oscillator being coupled to the first valve by the pick-up coil shown. From the secondary of the input transformer L_2L_3 the resultant oscillations pass to an intermediate frequency amplifying valve, thence to a detector, and thence to the low frequency amplifiers and loud speaker in the usual way. Another method is to cause the first valve circuit to also function as the oscillator, and to pass on the resultant output of this valve to the intermediate frequency amplifier, etc.

As an example of a modern high-grade superhet which also combines the latest in circuit design, valves, and components, we will take the *Philco Receiver*, one model of which is shown on page 249. This is a five valve all-mains (A.C.) receiver consisting of a pentagrid which combines the functions of modulator, oscillator, and intermediate frequency amplifier, a variable-mu radio-frequency pentode amplifier, a double-diode-triode for rectification, audio-frequency amplification, and A.V.C., a 3 watt pentode output, and a full-wave rectifier. The pentagrid is a wonderfully efficient multi-purpose valve. The grid nearest the cathode is the oscillator control grid, the next is the oscillator anode and modulating grid, the next screens the oscillator section of the valve, the next receives the input signal from the aerial, and the last acts as the usual screen for the screened grid portion of the valve. In working, the third grid is positive with respect to the cathode, so that the stream of electrons passing through the first grid is not all absorbed by the second grid: a proportion is attracted by the third grid and passes through towards the fourth. But this latter is biased to a

negative potential so that the electron stream is repelled forming an electron cloud between the third and fourth grids. This cloud forms a *virtual cathode* for working the outer elements of the valve, and as it varies in density with the changes on the first grid, any signal impressed on the fourth grid will be modulated accordingly. The rectified output of the double-diode-triode is applied to a resistance: the A.F. voltages developed across this are fed to the grid of the triode portion of this valve for amplification and passing-on to the next valve, while the D.C. potential appearing across it is fed back to the control grids of the preceding valves for A.V.C. The amplification factor of the radio-frequency pentode is nearly 1000.

The speaker is of the electro-dynamic moving coil type and is transformer fed. A four point *tone-control* is provided giving "brilliant," "bright," "mellow" or "deep" tone, according to taste. There are in all seven tuned circuits, ganged and controlled by one knob. The on-off switch also provides volume control: separate reaction is not employed. The chassis floats on rubber to overcome microphonic vibration which might result in vibration of the tuning condensers. The essential parts are metal enclosed; good screening is provided throughout. The back of the receiver is open to allow free circulation of air and ready dissipation of heat, and to avoid that muffled sound found in the case of powerful receivers completely cabinet enclosed. Arrangements for fitting a gramophone pick-up are incorporated. *Shadow tuning* is employed, *i.e.* a shadow indicates to the eye when a station is *exactly* tuned in. The working of the receiver is simplicity itself —one tuning control, one volume control, one wave-change switch, one tone control (four point)—and the A.V.C. is operated by the receiver itself. We mention these points to show that the superhet principle can be, and is here, combined with all modern circuit improvements.

For many years we have been advocates of the superhet —in the early days because of the inefficiency of the then existing high frequency amplification—in later days because of the increasing difficulty of selectivity with an over-crowded

aether. Early superhets were big, costly affairs—eight or nine valves at twenty-five shillings each—difficult to build, and tricky to operate. But modern improvements all round have remedied that. *Superhets are now to the front.*

A few test details of the receiver we have just described will be interesting and, incidentally, will support our contention as to the value of a superhet. Its performance is amazing. It seems to meet all reception needs on both long and medium waves giving brilliant results as to volume, selectivity, range, and tone quality on all stations likely to be required.

In Cambridge over 100 stations were received at good volume: in fact the volume control must be kept well down for the usual English stations and the more powerful foreigners. Selectivity without side-band cut-off, and range are, alike, outstanding features of the set. With the London Regional full on at great volume, a very small movement of the dial almost eliminated it, a further slight movement brought silence, and then Muhlacker was brought in at full strength: but there was no interference between the two. It was equally easy to separate Wusterhausen from Radio Paris and London. Metala was clear of Warsaw, and Warsaw gave no back-ground from Eiffel Tower. Within twelve miles of Brookmans Park, Brussels, Rome, Vienna, Prague, Leningrad, Osla, and others came in at wonderful volume and clearness without interference. Even the small transmitters—Kiel, Cork, Juan-les-Pins, etc.—were received at good volume. Reproduction of speech and music are alike of "quality." Speech is crisp without slurring of sibilants. The bass response is very good, clear without boom, and well defined, and there is a pleasant balance of tone throughout the whole musical range. The speaker is capable of handling great volume without any signs of distress or unpleasant resonance. The tone control is smooth and nicely graded, and A.V.C. is really automatic and efficient, levelling up the volume on all stations to the listener's liking as determined by the hand control. And the shadow tuning, enabling a station to be exactly tuned " in silence," is a boon. A " quality "

receiver of the front rank, with volume, range, selectivity, and sensitivity of an unusually high order—a receiver to be recommended.

Another Philco Superhet is of special interest, viz. a seven valve "all-wave" model on which, in addition to the whole range of medium and long-wave stations, short-wave stations in all parts of the world can be heard with marked fidelity and at excellent volume. Yet the manipulation of the receiver is simplicity itself. A wave band switch brings a separate illuminated tuning-dial into view for each of the wave channels—long-, medium-, and short-wave bands: the remaining three dials are the on-off switch and volume control, the tuning control (the shadow tuning device is again incorporated), and the tone control. The valves employed in the receiver are a full wave rectifier, a radio-frequency amplifier, an oscillator and first detector, an intermediate frequency amplifier, a second detector and audio-frequency amplifier (with A.V.C.), and two output pentodes (push-pull). The long-wave band is from 860 to 2070 metres, the medium band from 174 to 560 metres, and the short-wave band from about 16 to 53 metres. The tuning control is fitted with a small central knob which gives a low gearing and therefore slow motion, so that very accurate tuning can be carried out. The speaker is of the electro-dynamic moving coil type. As with the previous model, the performance of this all-wave superhet is excellent no matter from what stand-point it is judged. It is extremely selective and sensitive on all bands—long, medium, and short. On the ordinary waves the receiver displays that same exceptionally high standard we have previously indicated. The latest Philco covers the range of short waves from 17 metres to 170 metres. Most makers now have excellent "all wave" superhet models.

We have described these in detail for they amply demonstrate what we have always contended, that for powerful sets the superhet principle, combined with the latest ideas on circuit design and backed by the high-grade matched components of to-day, *can produce* a set of unlimited range, marked selectivity without side-band cut-off, excellent

tonal qualities and fidelity in reproduction, and simplicity of control, which will satisfactorily handle the complex, present-day broadcasting conditions. And their excellence is maintained down to the short and ultra-short waves.

4. The General Principles of Television.

Television, as you know, is the transmission "by wireless" of the image of a living person or of a place, etc.

There is a distinct connection between sound broadcasting from the studio to the *listener*, and television

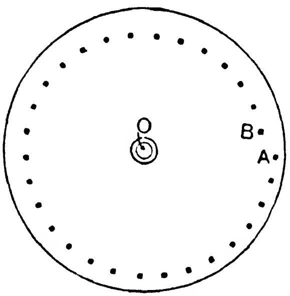


Fig. 216.

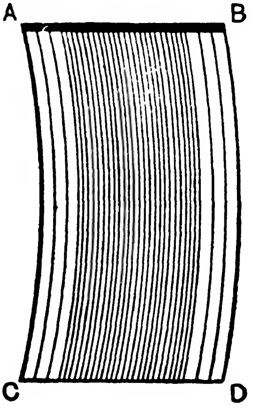


Fig. 217.

broadcasting from the studio to the *observer*. The scientific principles are much the same, and the practical working is much the same, in both; in fact "wireless" transmitters, "wireless" aerials and earths, "wireless" waves, "wireless" receivers and "wireless" accessories, are used in television just as they are used in sound broadcasting and reception. But several details and necessary conditions differ.

For the reception of television you require a wireless receiver, but instead of using a loud speaker to convert the output varying current into sound, you require what in the Baird system is called a "televisor" to convert the varying current into a picture of the person televised.

One method in the Baird System uses a *scanning disc*, as it is called: in another, the disc was replaced by a *drum fitted with a number of mirrors*. We will take the former, and explain the principles first by reference to the late *low-definition* system, as it is called.

The Baird scanning disc method is as follows:—A disc with 30 holes rotates in front of a lamp at a speed of 750 revolutions per minute. The disc holes are arranged in a spiral, each hole being a little nearer the centre than the one in front of it as shown in Fig. 216. (Holes 1-3 and 28-30 are rectangular.)

As the disc rotates the first hole comes into the light beam from the lamp and travels upwards through the beam. During this upward journey light passes through the hole so that a " light-spot " sweeps up, say, the face of the person to be televised who is sitting facing the disc. When the first hole passes out of the light beam at the top, the second hole comes into the beam at the bottom and travels upwards through the beam so that another light-spot sweeps up the face of the person. As, however, the second hole is a little nearer the centre of the disc, the second vertical journey of a light-spot over the face is a little to the left of the vertical journey made by the light-spot from the first hole. This action is repeated by each hole in turn so that by the time the disc has made one revolution 30 more or less vertical light journeys will have been made over the face. The holes are so arranged that the light strips just touch each other as shown in Fig. 217. And although the whole face is traversed in this way nearly 13 times per second only one light spot is on the face at any one instant.

Now the face reflects and scatters the light falling on it, the amount of light thrown back at any instant depending on where the light-spot happens to be at that instant: thus more light will be scattered by the teeth than by the cheek, and more by the cheek than by the hair or eye-brows.

This *varying light* scattered by the face falls upon the cathode of a special cell known as a *photo-electric cell*

suitably placed to receive it. Fig. 218 shows the principle of this photo-electric cell. A is the cathode (a plate coated with caesium) and B is the anode (grid of metal). The vessel is exhausted of air (or contains the inert gas helium) and is joined to a battery as shown: thus B is at a higher potential than A, but no current passes for the space is an insulator.

Now when light falls on the cathode of such a cell it gives off electrons and an electronic current flows in the direction A to B through the cell and B to A through the wires, etc. (the conventional current goes the other way). Moreover an intense beam of light causes a bigger ejection of electrons and therefore a bigger current than a weak beam. Thus if the light falling on A is light scattered from the brow of the person being televised, the cell gives a greater current than it does when the light is scattered by the eye-brows. Clearly then as the face is scanned by the spot light we get a varying current from the cell depending on the varying light scattered by the face. This varying current—depending on "the face" and not on "words or music"—is then treated in the same way as the varying current from the microphone in ordinary broadcasting: it is amplified, passed to the transmitter, and modulates the carrier wave.

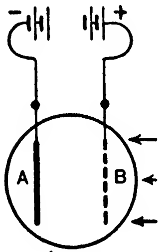


Fig. 218.

At the receiving end the modulated wave sets up corresponding electrical oscillations in the aerial and these are conducted to, and dealt with by, a wireless receiver in the usual way, only the output instead of being passed to a loud speaker is passed to what Baird calls a "televisor." This appliance (Fig. 219) consists of a neon lamp N (see below), a disc S exactly like the scanning disc at the sending end (*i.e.* provided with 30 holes in a spiral and rotating at 750 revolutions per minute), and an arrangement of lens for viewing the neon through the holes of the disc as the latter rotates. The televisor of course also includes a motor for driving the disc at the correct speed.

The neon lamp consists of two nickel electrodes in a glass vessel containing rarified neon gas. If the plates be joined to the poles of a H.T. battery (K to the negative pole) and a P.D. of about 200 volts be applied a discharge passes through the lamp and the back of K becomes of a yellowish-orange colour. If when this glow is on we increase the voltage the glow becomes more intense and if we lessen the voltage the glow becomes less intense. Clearly, then, the varying current from the wireless receiver will produce varying pressures on the neon and therefore a varying illumination on K. It is on the back of K, viewed through

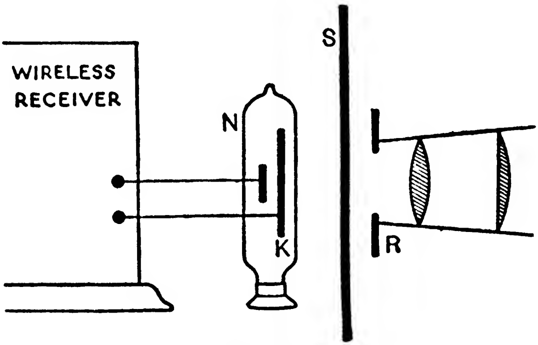


Fig. 219.

the lenses shown (Fig. 219) that the picture of the face televised is built up.

Suppose hole 1 of the transmitter moves upwards: then hole 1 of the receiver sweeps upwards in front of K, and the result is a varying current from the photo-electric cells (depending on the light and shade at each point of the face as the light-spot sweeps upwards), a modulated aether wave, a corresponding varying current through the wireless receiver, and corresponding varying extra pressures applied to the terminals of the neon lamp: and the result of this is a varying illumination on the plate K. The illumination of K at any instant, and therefore the light which comes through the hole to the eye at that instant,

depends on the light thrown back by the part of the face opposite the hole of the transmitter at that same instant. (Remember also that the two holes are in corresponding positions at each instant.) All this applies to each hole as the two discs rotate.

Now the two discs are moving at a speed of 12½ revolutions per second so that the varying illumination due to the whole face appears on K of the neon over 12 times in one second. At the cinema separate pictures are run through the projector at the rate of 22 or more per second, but owing to "persistence of vision" of the human eye the appearance on the screen is that of continuous movement and not a jerky movement of still pictures one after the other as it really is. So in this case: anyone looking into the televisor at the disc and the back of K will not see the disc holes separately or the disc moving at all, but he will see an entire illumination built up of the various illuminations properly spaced out and positioned, the whole forming a picture of the face at the transmitting end.

The motor and disc at the televisor must run at the same speed and be "in step" with those at the transmitter—they must be *synchronised* as we say. This seems an exacting demand when the two are separated by hundreds of miles, but Baird's system is quite simple—he uses in fact the "picture current" itself to do this—but we cannot go into details here.

Of course, if the person being televised also obliges us with a song or speech, well and good—that part is dealt with by the microphone at the sending end and received by our loud speakers in the usual way. The B.B.C. sent the "vision" out on the National and the "sound" on the Midland.

5. Modern High-Definition Television.

The greater the number of strips into which the scene televised is dissected by the scanning device, *i.e.* the greater the number of "scanning lines," as we term them, the more detailed is the picture received or the higher is the "definition." Television systems using up to 40

scanning lines are generally referred to as low-definition systems, those using between 40 and 100 as medium-definition systems, and those using above 100 as high-definition systems. The Television Committee in their report on the establishment of a high-definition service in this country suggested (practically) 240-line scanning: Baird's system for the high-definition service used 240-line scanning, and Marconi E.M.I. uses 405.

In the low-definition (L.D.) system we have dealt with the scanning was done *vertically* (with 30 lines). In the new high-definition (H.D.) system the scanning is done *horizontally* (with 240 lines, say). In the L.D. system the lamp was opposite a side rim of the disc so that when the latter rotated the holes swept *upwards* through the beam of light. If the perforated disc scanner (holes in a spiral) be used in the new H.D. service, the lamp must be opposite the top rim of the disc, so that as it rotates the holes will sweep *horizontally* through the beam from the lamp.

L.D. television (30 lines) can be transmitted on the same waves as are used for sound broadcasting, but H.D. cannot. On page 142 we referred to "side-bands" in sound broadcasting, and pointed out that in order to provide the side-band allowance, sound broadcasting stations were separated from each other by 9000 cycles or 9 kilocycles frequency. Now it can be shown that H.D. television demands a frequency space of the order of 1,000,000 cycles (1000 kilocycles) or so on each side of the carrier frequency—a total space of 2000 kilocycles—to accommodate the modulation effects: hence it cannot be sent out on our ordinary broadcasting waves which only allow 9 kilocycles separation between stations.

The medium band of waves in sound broadcasting comprises waves from 200-500 metres wave-length, *i.e.* frequencies from (300,000 ÷ 200) = 1500 to 600 kilocycles —a frequency space of only 900 kilocycles; and in this band there are about 100 sound broadcasting stations. *One* H.D. television station worked (if it were technically possible) on one of these carriers, say on a 300-metre carrier, would require *more than* all this medium wave

space, and therefore would render all the medium wave broadcasting stations useless.

There is, however, plenty of elbow room for H.D. television if we use the ultra-short waves between 3 and 10 metres wave-length. The frequency space here is from $(300{,}000 \div 3) = 100{,}000$ kilocycles to 30,000 kilocycles, *i.e.* the space is 70,000 kilocycles—room for many stations with 1000 kilocycle sidebands.

In the new H.D. television from the Alexandra Palace the vision is sent out on a carrier of 6.6 metres wave-length, and the sound on 7.2 metres. A receiver for H.D. television is designed to reproduce both sound and vision, one aerial only being employed.

6. At the Sending End in High-Definition Television.

Various methods are in use for the televising process at the sending end, but only one or two can be briefly referred to here: for details some up-to-date book on Television must be consulted.

(1) THE SPOT-LIGHT METHOD.—The spot-light method (horizontal scanning) with the perforated disc is suitable for "close-ups"—announcers, lecturers, etc. The disc has 240 holes in a spiral, and rotates 25 times per second or 1500 times per minute, for in H.D. 25 pictures are sent per second instead of 12½. An alternative method is to use a disc with two spirals, 120 holes in each spiral, and to rotate the disc at 3000 revolutions per minute (a shutter device is arranged to automatically close one set of holes while the other set is doing the scanning). Baird now uses 4 spirals of 60 holes: speed 6000 r.p.m. The principle is that already explained.

(2) THE TALKING-FILM METHOD.—A talking film consists of a series of photographs arranged one above the other with a sound record—a series of lines of varying density—down one edge of the film. Each picture depicts a motion slightly after the preceding one, and these pictures pass through the cinema projector so rapidly that the eye sees on the screen a continuous movement and not

a passage of several pictures. The method of televising a film may be briefly indicated as follows:—

In Fig. 220 the lens A concentrates light from the arc lamp L on the film F, which is continuously moving downwards through the gate G from the film spool S at the top to another at the bottom. The separate pictures pass downwards through the gate G at the rate of 25 pictures per second. By means of the lenses B a real image of these pictures is projected on the top rim portion

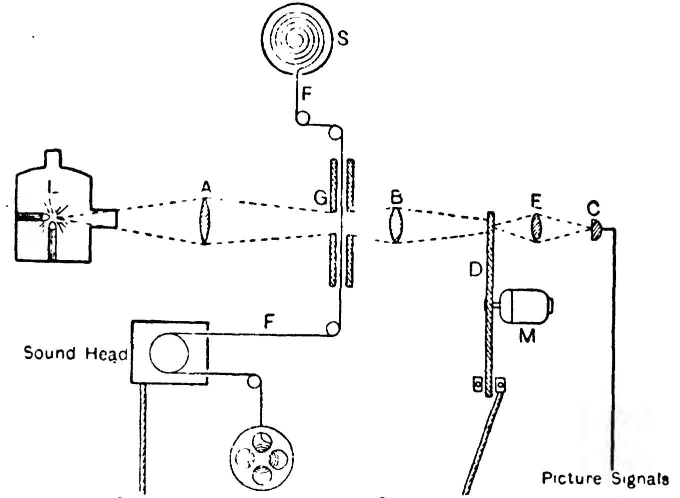


Fig. 220.

of a scanning disc D. As the disc rotates the holes will in turn pass across the image—in other words the image formed on the upper portion of the disc will be scanned horizontally—and wherever the hole happens to be at any instant a certain amount of light *will pass through it*, the amount depending on the light and shade of the part of the image where the hole happens to be at that instant.

The disc differs from the scanning disc dealt with in Art. 4 in the fact that the holes are arranged *in a circle*

instead of in the usual spiral formation of Fig. 216. But it must be remembered that the film itself is moving downwards through the gate, so that the image at D is also continuously moving vertically. Thus when the first hole completes its journey across, the second hole begins its journey, but during the first journey the image has moved vertically, so that the second hole's journey is over another portion of the image. By a suitable adjustment of dimensions, speed, etc., it can be arranged that the image is properly scanned in a series of horizontal lines " edge to edge " just as the person or scene is scanned in the spot-light method previously described.

The varying light coming through the holes—amounts depending on the light and shade of the various parts of

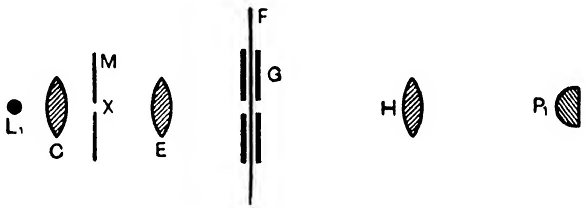


Fig. 221.

the image and therefore of the film—is focused by the lenses E on the *single* photo-electric cell C, which in turn gives a corresponding varying current; and this after amplification, etc., is *caused to modulate the carrier wave on which the vision is transmitted.*

For 240-line scanning the disc has 60 holes in a circle, and rotates 100 times per second. In $\frac{1}{25}$ second the disc will have made four revolutions, and therefore 240-line journeys across, and in this $\frac{1}{25}$ second one image-picture will have moved vertically. Thus we have 25 pictures transmitted per second, each being scanned by 240 lines.

Fig. 221 shows how the sound record down the edge of the film is dealt with, thus enabling the sound corresponding to the various pictures to be transmitted at the same time. In the figure, L_1 is a source of light, and C a lens which

concentrates the light on a narrow slot at X in the mask M. The lens E is so placed that it focuses an image of the slot on the sound record on the edge of the film which is continuously passing through G. The light which passes through the sound record meets the lens H by which it is concentrated on a photo-electric cell P_1. Clearly a varying amount of light depending on the varying density of the sound record, and therefore upon the words originally spoken, falls upon P_1 which, in consequence, gives a corresponding varying current. This varying current after being amplified, etc., is *caused to modulate the carrier wave on which the sound is transmitted.*

(3) The Intermediate Film Method.—The televising of objects by the method of Art. 4 is only suitable for "close-ups," but the *intermediate film method* enables large scenes, indoor or outdoor, to be dealt with; and the time-interval between the taking of the "shots" and the televising process is only about 30 seconds—a delay which is negligible.

In this method an *unexposed* film coated with a specially rapid and sensitive emulsion passes through a cinematograph camera, and the scene is photographed on the film —just as is done every day by the film people—25 exposures being made every second. At the same time microphones pick up the sounds and a sound record (a series of lines of varying density) is produced on the narrow strip down the edge of the film: this again is a procedure carried out every day in the film world.

From here the film passes into a processing tank fitted with three compartments containing the necessary solutions for developing, washing, and fixing. From the tank the film, still wet, passes down through a gate at the rate of 25 pictures per second, and here the television process begins exactly as described above for the television of a commercial talking film.

The wet film, after the scanning process, is usually passed into a storage tank, is dried, etc., and stored for future transmissions. An alternative method is to pass the film through further tanks where (*a*) the pictures are washed

off, (*b*) the film is re-emulsioned, (*c*) the film is dried; and then the film passes again to the camera for further "shots." Thus the one length of film is used over and over again which results in film economy.

(4) THE ELECTRON-IMAGE CAMERA METHOD.—So far the scanning methods we have dealt with have been of a mechanical nature—discs driven by motors. There are, however, systems based entirely on electrical scanning—methods which possess many advantages over mechanical devices. Of these the two best examples are the *electron image camera method* (pioneered by Baird in this country) and the *iconoscope camera method* (pioneered by Marconi E.M.I.). We cannot describe these fully in this book—here, again, some good book on Television must be consulted—but we will briefly indicate the *principle only* of one of them, viz. the electron image camera.

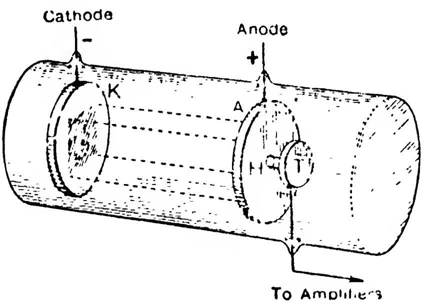


Fig. 222.

This system was first worked out by Farnsworth in America. Imagine a glass cylinder (Fig. 222) fitted with a cathode K (−ve) at one end, and an anode A (+ve) at the other end. A is pierced with a small hole H, and behind this hole is a conducting target or collector T. The inner surface of K is coated with caesium just as is the cathode of a photo-electric cell. An image of the scene to be televised is focused, by photographic lenses in the usual way, on the photo-electric surface of K. The result is that the surface of K ejects electrons, the number ejected from any part depending on the amount of light producing that part of the image. As the anode A is at a positive potential the (negative) electrons will be attracted towards it so that we have what we might call an "electron beam"

passing along the tube. Moreover, we will suppose the electrons keep their proper formation all the way along the beam. At any section of the beam we will have an "electron image"—an image made up of electrons—which bears a true relation to the light and shade of the image at K, and therefore to the scene televised.

Now consider the electron image in the beam at A. A particular part of the image will fall at the hole H and the electrons of that part will pass through and be received by the collector T. If another part of the image fell at H a different number of electrons would pass through to T. It is clear, then, that if we could move that hole horizontally across the electron image, then *very quickly* get it back again, then move it horizontally across again, this second journey being edge to edge with the first one, and so on, the varying numbers of electrons passing through H to T would form our "picture signal" which could be taken from T to amplifiers and finally caused to modulate the carrier wave on which the vision is sent out. In fact we want to scan the electron image at A by 240 scanning lines, and we want to keep on doing it at the rate of 25 complete scans (each of 240 lines) per second.

This is what is done, but instead of moving the hole over the image, the whole electron beam (and image) is moved over the hole. The movement of the image is brought about by two pairs of current-carrying coils suitably arranged outside the tube. One pair brings about the horizontal movement of the image across the hole, and the other pair brings about the vertical movement of the image, thus obtaining the necessary edge-to-edge position of the successive scanning lines.

There are many refinements in the construction of the actual camera, not the least of which is a device for amplifying the picture signals known as the *electron multiplier*.

(5) THE ICONOSCOPE CAMERA METHOD.—This, like the *electron camera* of Baird, is an all electric system, and it has been developed in this country by the Marconi E.M.I. in

what is called the *emitron camera*: it is in use at the Alexandra Palace television station.

The iconoscope consists of an evacuated glass vessel (Fig. 222 (*a*)), at the extreme narrow end of which is a cathode which is heated. In front of the cathode is an anode (or two) each pierced with a hole at the centre and maintained, of course, at a positive potential. The electrons given off by the cathode are attracted by, and accelerated towards, the anode, so that we have a very narrow beam of electrons shooting through the anode holes

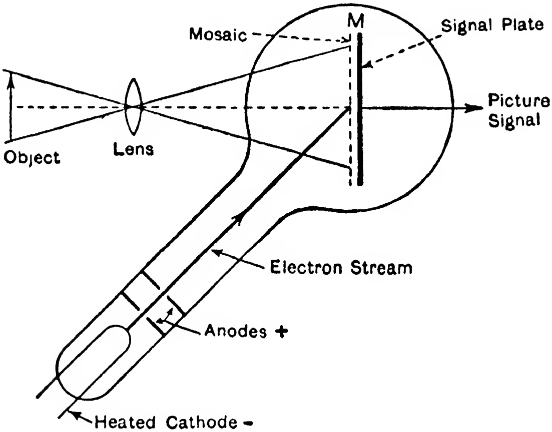


Fig. 222 (*a*).

and going straight on into the wider part of the tube. It is this narrow beam of electrons which is used to do the "scanning" operations.

Situated in the wide portion of the tube is a plate-electrode M on which an optical image of the scene to be televised is focused by photographic lenses in the usual way. M consists of a thin sheet of mica backed by a sheet of metal known as the *signal plate*. The front surface of the mica is first sprayed with silver oxide powder which is then heated and reduced to silver in the form of *tiny*

globules: these are next oxidised so that they are insulated from each other, and then they are given a coating of caesium. Thus the front of the mica sheet is a "mosaic" of a tremendous number of tiny silver globules all insulated from each other, and each made sensitive to light, like the cathode of a photo-electric cell, by the coating of caesium.

Notice also that *each* silver globule forms, with the signal plate behind and the mica between, a small condenser. When therefore an optical image of the scene is projected on M each element of the surface ejects electrons according to the light and shade of that part of the image which falls on it, and each tiny condenser is therefore "charged" accordingly. We have a "picture" on M made up of "charges."

The narrow electron beam coming up from the cathode is now caused to scan the surface of M in the usual way, *i.e.* horizontally and vertically. The beam is moved over M just as the electron image beam was moved over the hole in the image dissector: and it is done in the same way, that is by two pairs of coils suitably placed outside the tube and carrying the necessary varying currents.

Consider then the scanning electron beam coming for an instant on one of the tiny condenser elements. Electrons (negative) pass from the beam into the condenser, completely discharging it, and consequently an equal current impulse appears at the signal plate behind. This happens with each element in turn as the electron beam scans the surface of M. Thus during the scanning we get a varying current in the signal plate circuit, the current at any instant depending on the charge on the tiny condenser which the electron beam happens to be discharging at that instant, which again depends on the light and shade of the part of the image there. In short, we get a corresponding current picture signal in the signal plate circuit: this picture signal is passed to amplifiers, etc., and finally modulates the carrier wave on which the vision is sent out.

Both the electron camera (Baird) and the emitron camera (Marconi E.M.I.) are contained in single camera structures much the same as the cameras used in film

studios. Incidentally, the E.M.I. use a scanning method known as *interlaced*, but we need not give details here.

Fig. 223. A Cossor High Vacuum Cathode-Ray Tube for High-Definition Television. This tube is 12½ inches in diameter.

7. At the Receiving End in High-Definition Television

Here, as at the sending end, we encounter both mechanical and purely electrical devices, but in this case there seems little doubt but that the electrical method which employs what is

called the *cathode-ray tube* is best adapted for the purpose. Again, however, we can only indicate the general principle.

The cathode-ray tube is shown in Fig. 223, and the picture is built up on the large, circular, and nearly flat end of the tube. At the extreme narrow end of the tube is a filament cathode (or kathode) which is heated by a current, and gives off electrons just as does the filament of a valve. In front of the cathode (Fig. 224) is a disc anode A_1 (pierced with a hole), a second anode A_2 in the form of a cylinder, and a third anode A_3 in the form of a disc with a central hole. These anodes are at positive potentials, A_3 being at a higher potential than A_2, and A_2 higher than A_1. The positive anodes attract the electrons, the result being that we have a narrow stream of electrons shooting through the anode holes and passing on to strike

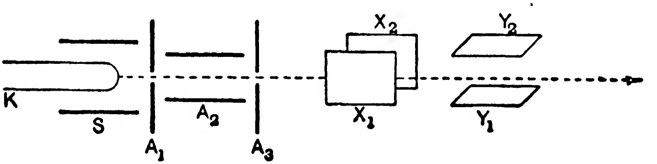


Fig. 224.

the end of the tube. Moreover a cylinder S (called the shield) surrounds K, and is given a negative bias: it therefore repels the electrons and squeezes them into a narrow beam to pass along the axis. The effect of the various anodes is to focus the beam at the end where it strikes.

The end of the tube is coated with a fluorescent material, *i.e.* a material which glows when hit by electrons, so that we get a bright patch of light on the fluorescent material—the screen, as it is called—at the point where the cathode-ray stream strikes it, and the more intense the stream the brighter is the patch of light. If the end of the stream be quickly moved horizontally along the screen we see (by persistence of vision) a bright line, and so on.

Now, in practice, the cathode-stream is caused to "scan" the end of the tube in the manner we have already indicated. It is moved along the first line, and then is very rapidly triggered back to begin its second line journey, this journey being edge to edge with the first one, and so on. When 240 lines have been traced in this way it is rapidly triggered back to the starting point to begin its second complete scan, and this continues at the rate of 25 complete scans per second. These movements are brought about by two pairs of deflecting plates X_1X_2 and Y_1Y_2 to which varying potentials are given in order to move the electrons about as required. The result so far, then, is that by persistence of vision we see on the screen, not a moving spot of light, but a complete area of light.

Finally, the output of the receiver, *i.e.* the picture signal, is passed to the shield S. This varies the potential of S, varies its effect on the electron stream, and varies, therefore, the intensity of the stream. Thus we get a varying illumination on the screen depending on the varying signal from the receiver—in other words, an image of the object televised is built up on the screen.

This account of television is necessarily very brief: for details some book on the subject must be consulted.

8. Tele-Photography.

Tele-photography—the transmission of photographs by wire and wireless—is now used by many of the leading newspapers, and as it is a related subject to television a brief reference may be made to it. Three systems are mainly in use, viz. the "Siemens-Karolus-Telefunken," the "Belin," and the "Bell." We will take the Bell system.

At the sending end the photograph, prepared in the form of a transparency, is mounted on a cylinder which, while rotating, is, by a screw mechanism, moved slowly along in the direction of its axis. A light-spot, which has the same width as the thread of the screw is focused on the photographic transparency, and as a result of the two movements referred to, the whole picture is scanned in the

form of fine, close, parallel strips. Clearly the amount of light transmitted through the picture (or in some systems the amount reflected from it) at any moment will depend on the density of the part of the picture being scanned at that moment. This varying light falls on the cathode of a photo-electric cell and a varying current is produced which after amplification is passed to line or caused to modulate a carrier wave in the usual way.

At the receiving end the varying currents are amplified and then passed into what is called a " light valve " (don't confuse this with the thermionic " valve " already dealt with). The light valve merely consists of a metal ribbon strung in a magnetic field due to a large " field coil." Light from a lamp passes through a hole in the field coil and falls on the ribbon. By means of two movable jaws the size of this hole is so adjusted that when the ribbon is stationary it completely covers the opening so that no light can pass through to the other side.

Now when the incoming varying picture currents pass through, the ribbon vibrates under the alternate polarities as you will understand from what we said in Chapter I., and in so doing it no longer blocks up the opening—some light passes through. The amount passing through varies with the vibration of the ribbon and therefore varies with the varying current received. In other words we get a light passing through which varies in proportion to the current from the photo-electric cell at the sending end and therefore in proportion to the light through the photograph being transmitted. The varying light from the light valve is finally focused on to a photographic film mounted on a cylinder which is rotating and advancing in synchronism with the photograph and cylinder at the sending end. Thus the photograph is reproduced.

9. Special Aerials. Directional Work. Direction Finding

We mentioned in Chapter VII. that an aerial has its *natural wave length* and would pick up signals (without any tuner) of the same length as its own natural wave length. This wave length is governed by many factors in practice.

As a rough guide for our purpose, however, we may take it that if we had a *thin vertical wire* as an aerial, its natural wave length would be about 4·2 times the length of the wire itself: in other words we might say that the aerial is *one-quarter* of the natural wave length.

Now in ordinary sound broadcasting (long and medium waves) the dimensions of the receiving aerial are not vitally critical (within reason, of course), and those described in Chapter VII. are quite suitable. When we come to short and ultra-short wave aerials, however, some attempt at "making them to measure" should be carried out, a certain "range," of course, being again covered by tuners in the usual way.

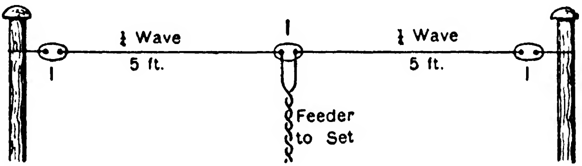


Fig. 225.

(1) HALF-WAVE DIPOLE AERIALS.—A popular aerial for such reception is some form of "doublet," as they are called, and the *general principle* will be gathered from Fig. 225. Here, however, we have taken an aerial—usually referred to as a *half-wave dipole*—suitable for the reception of the ultra-short waves used in television, but the general idea also applies to the "shorts." Assuming, for simplicity, a transmitting wave length of 6 metres or 20 ft. approximately (actually vision is sent out on 6·6 and sound on 7·2 metres), this means a total aerial length of 10 feet. The aerial is in two halves, in line, end to end, the ends being 2-3 inches apart, so that each arm (Fig. 225) will be one *quarter of a wave length, i.e.* 5 ft.: in the figure I, I, I are insulators. A "feeder" from the two inner ends to the receiver in the house may consist of twisted flex (rubber covered). At the house end of the feeder we have the *two ends* of the flex to couple up to the receiver: the most

satisfactory way is to join the two ends to a single or double turn coil which is "coupled" to the first grid coil of the receiver. Instead of a twisted flex feeder two separate wires may be used, keeping them parallel throughout their entire lengths and 2-3 inches apart by suitable spreaders.

Another method is shown in Fig. 226. The two parts of the aerial are of copper *rod* or *tube* of about ¼ inch diameter, and lengths of 5 feet of this are self-supporting.

Similarly for, say, 20 metre reception: each half of the aerial would be 5 metres or about 16 feet, and so on. A better feeder arrangement is to keep the wires apart, but at regular intervals to *cross them over*: this eliminates interference. *Double dipole aerials* to cover a wider range, and *multiple dipoles* to cover a very wide range including the ordinary broadcast bands, are also available.

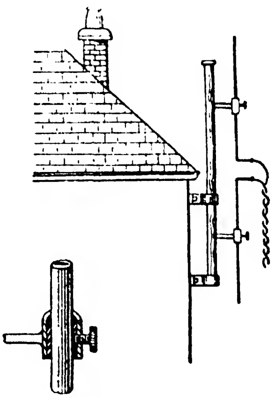


Fig. 226.

(2) Noise-Free All-Wave Aerials.—We have referred to the interference of one station with another, but modern receivers are so selective that this has been cut down to a minimum. There is often, however, another type of interference with reception in the form of background noises, cracks, crackles, etc., which are really due to various forms of electrical machinery in the vicinity—tramcars, trolley buses, motor car ignition, vacuum cleaners, electric signs, dental and medical electric appliances, electric lifts, workshop motors, and so on.

We might say that all the above act like miniature wireless transmitters. When electrical disturbances are generated by a motor, say, they are radiated away, or they travel back along the mains joined to the machine—usually they do both. Of the former, some may be

directly picked up by your aerial and down lead; some may be picked up by your house wiring and be re-radiated to your aerial, etc.; some may be picked up by telephone wires, trolley wires, etc., and again be re-radiated, and so on. Of the mains conducted interference, some will enter the set by the set lead if the receiver be mains driven, and some may be re-radiated from the house wiring as in the cases above. To eliminate most of the above we must, somehow, get our aerial arrangement protected from radiated and re-radiated interference.

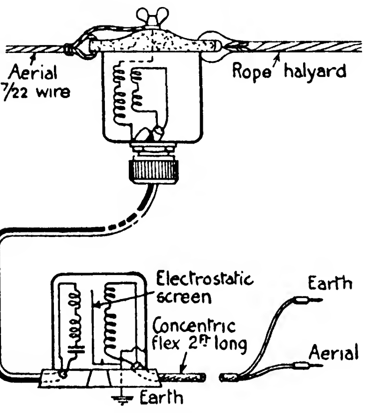


Fig. 227.

Now this field of interference gets weaker the further the distance from the radiating source, and can rarely be detected at a greater height than 25 or 30 feet: hence the first point is to have the aerial proper high enough to be outside the interference field. The down lead, however, will pass through the danger zone and will pick up the interference, and means must be devised to so protect the down lead that it cannot do this.

Several noise-free aerials—many " all wave "—have been devised for the purpose, and we will take the Belling and Lee " Eliminoise " aerial in illustration. We have ourselves tested it, not only in our own home (where conditions are certainly worse than the average), but also on a site where the interference is normally decidedly pronounced (due to X-ray and violet ray apparatus, laboratory electrical machinery of all types A.C. and D.C., an adjacent engineering workshop, and nearby motor traffic), and we have formed a very high opinion of it: it is remarkably effective

in every way, and *we can thoroughly recommend it* for we feel certain it will give every satisfaction.

Fig. 227 will show the construction. The usual horizontal aerial wire AB of Fig. 114 is used: this should be erected above the interference field, its near end A should be as far from the building as possible, and its length should be about 60 feet (and not less than 40 feet). The end A of the aerial is joined to the primary of a high frequency step-down transformer: both the primary and the secondary consist of short and long wave windings wound on the same former. The secondary is joined to a special transmission line (feeder). This consists of two conductors thoroughly insulated and covered with a *metal braided shield* over which is another sheath of special rubber for water-proofing purposes. The metal shield is earthed, and *this shielding prevents the transmission line from "picking up" on its way through the danger zone*: signals of whatever nature are only picked up by the aerial proper which is outside the field of interference. A step-up transformer is arranged near the receiver and the two conductors of the transmission line are joined to its primary, the secondary being joined to the aerial and earth terminals of the set.

The technical details of construction to secure proper *matching* and a *good response* over practically the whole band of wave lengths—long, medium, and short—have been very carefully investigated and carried out by the makers *with decidedly outstanding success*. The slight loss in signal strength (only the aerial—not the lead-in as is usual—picks up signals) is so very slight as to be undetectable by the ear: it is absolutely negligible.

In the Philco noise-free all-wave aerial there is an aerial transformer, a set transformer, and a screened transmission line as above, but the aerial consists of two horizontal parts in line stretching away (opposite directions) from the aerial transformer: one part is 17 feet long, the other about 40 feet. Other makes are on the market.

(3) DIRECTIONAL WORK AND DIRECTION FINDING.—Directional transmission and reception and wireless

direction finding are important for navigation purposes—ship and aviation alike. With suitable apparatus an aeroplane, for example, might find the *directions* of, say, two land stations and, the position of these two stations being known, the aeroplane operator would be able to determine the aeroplane's position. Similarly, land stations with suitable apparatus might locate the *direction* of an aeroplane relative to each of them and so inform the operator so that the aeroplane's position would again be determined.

There are many types of directional apparatus, but we can only indicate one or two general principles in this book.

Going back to Fig. 122, it will be remembered that with the frame aerial in the position (*a*) we got maximum reception, and in position (*b*) minimum reception: the same general principle holds in transmission, and was utilised in an early form of aerial for *directional transmission* by Bellini and Tosi.

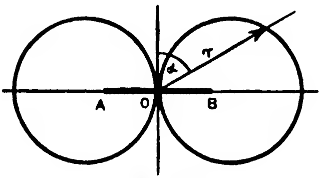


Fig. 228.

Consider an aerial consisting of a vertical triangle of wire, the vertical sides not connected at the top, and the base containing the transmitting circuit. The radiation will be mainly *in the plane of the triangle*, so that if AB (Fig. 228) depicts the base of the triangle, the radiation will be mainly to the right and left, and can be approximately represented by the two circles (we might say by a figure 8); the radiation right and left is represented by the diameter of the circle, the radiation in the direction of *r* is represented by the chord *r*, the radiation at right angles to AB (*i.e.* to the plane of the triangle) at O is zero, and so on: such a diagram when properly constructed is known as a *polar diagram*.

Now consider two such triangular aerials fixed at right angles to each other, with another aerial—a simple vertical aerial—at the centre of the triangles. Suppose the vertical aerial and one of the triangular aerials radiate. The

triangular aerial will give the figure 8 for polar diagram, and the vertical aerial will give a circle, since it radiates equally in all directions: these are shown at A and B respectively (Fig. 229). By having a suitable phase difference between the currents in the two aerials (see below) the resultant of A and B is given by the curve C (attention is paid to the "signs" of the radiation in the A and B curves in plotting the C curve): the energy radiated is mainly in the plane of the triangle *but largely off to one end.*

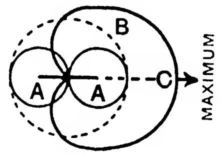


Fig. 229.

Imagine now that the vertical aerial and the other triangular aerial radiate. The result will be similar, but the A curve, the 8, will be turned through 90°, and so will the resultant radiation as given by the curve C.

The Bellini-Tosi directional aerial for transmission is based on this, and is indicated *in principle* in Fig. 230. The two triangular aerials are at right angles, and the vertical aerial includes a pivoted coil in which the oscillations are set up. If this coil be placed parallel to one triangle P and thus coupled with its coil, the coupling with the coil of the other triangle Q will be a minimum; hence Q will not be acting at all, the radiation will be from P and the vertical aerial, and the resultant will be as shown in Fig. 229. If the pivoted coil be parallel to the other triangle Q and thus coupled with its coil, the coupling with P will be a minimum: hence P will not be acting, the radiation will be from Q and the vertical aerial, and the resultant will be as shown in Fig. 229, *but moved through* 90°. For intermediate positions of the moving coil both triangles will be acting by an amount depending on their relative coupling. Thus by rotating the coil, energy may be

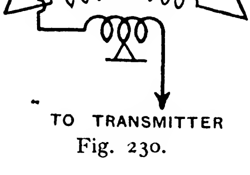


Fig. 230.

transferred to either aerial, or to both in any proportion, and maximum radiation sent out in any particular direction.

A little digression. Note the following elementary facts to help you with the above and what follows:—(*a*) Going back to the facts of current induction in Fig. 53, remember that starting or increasing a current from C to D caused induced current from B to A (opposite), whilst stopping or decreasing the C to D current caused current from A to B. (*b*) A Bellini-Tosi triangle radiates *backward* as well as forward (figure eight), but by using also a centre vertical aerial carrying current really 90° out of phase with the side aerials they prevented the backward waste. (*c*) With two coils A and B at right angles at their centres and both "sending out" in their respective planes, B, for example, does not radiate along the plane of A, for it is at right angles to it: B's current might be reversed without affecting the signal *received by a station exactly in line with* A. Think about these points.

To proceed. Several "beacon stations" have been erected for navigational purposes: they "send out" in constantly varying directions just as some lighthouses use a revolving light beam. Imagine a coil aerial at one of these stations capable of rotation. It radiates *maximum* energy in the plane of the coil but *none* at right angles to the plane at its centre. Suppose it rotates, say, at one revolution per minute, and that every time the plane of the coil is due north and south it sends out a *distinctive* signal. Imagine a wireless observer, say on a ship, starts a stop watch when he receives this signal (he knows that at that instant the transmitting coil is pointing, say, north). Imagine now that he waits until he receives *his strongest signal* and then stops the watch (he knows the coil is then pointing towards him). Knowing the time between the two signals and the speed of rotation of the transmitting coil, he obtains the angle the coil has turned through from its N and S position, and therefore gets his bearing from the station. In practice it is usual to note the *minimum*, not the maximum, signal and to work the angle out accordingly.

Several beacon stations round our coast send out beams of *short* waves reflected by parabolic reflectors which are caused to revolve. A definite signal is sent out, say for every point of the compass, and ships are fitted with the necessary short wave receiving apparatus so that they can ascertain their bearings relative to these beacon stations. This obviates the necessity of "timing" between a distinctive signal and a *maximum* or *minimum* signal as explained above.

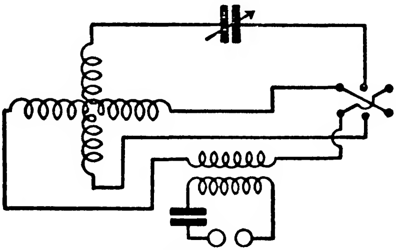


Fig. 231.

A transmitting method which has been developed by the R.A.F. uses two coils at right angles (Fig. 231). They are joined in series through a tuning condenser, and a reversing switch: power is supplied to the aerial arrangement through a coupling coil. The aerial system is rotated at, say, one revolution every minute, and the reversing switch is operated continuously at two to four times a second. When either of the coils is pointing towards a receiving station successive signals are of equal intensity; in other positions they are not (see [*c*] above). The observer is thus able to tell when one of the coils is pointing at him. A special signal is sent out when the coils are in a definite direction so that the observer can determine the relative direction of the transmitting station. One of the frame coils is made larger than the other so that during a rotation of 180° there are *two sets* of successive equal

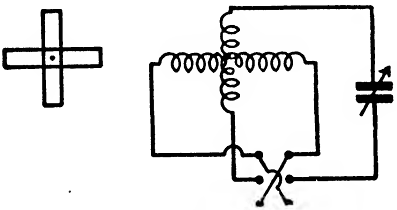


Fig. 232.

signals, *one set* stronger than the other. Thus the observer knows which coil is pointing at him.

Finding the position of a wireless station by *directional reception* is now much more common than by directional transmission methods. One of the early methods was due to Bellini and Tosi and was a modification of their transmission method, the aerials, however, being closed loops: we need not, however, go into details. A directional reception system known as the Robinson system is much used in the R.A.F. It consists of two coils (Fig. 232) fixed at right angles but capable of rotation about a vertical axis. The two coils are in series, but the connections of one—call it coil A—can be reversed. When A is at right angles to the direction in which the waves are coming, no E.M.F. will be induced in it, and therefore there will be no alteration in the strength of the signals received by the other coil—say B—when the reversing switch connected to A is worked. When this occurs, then B is pointing in the direction of the waves and A at right angles to them. The system is very suitable for aeroplanes where the noise level is high, for the observer is not listening for maximum or minimum signals.

There are several sources of error in directional work which have to be compensated for, *e.g.* induced currents in the metal work of the ships and aeroplanes, etc. It is found, too, that the "bearings" of a station vary somewhat according to the time of day and night: these *night effects* are due to variations in the reflecting layers of the atmosphere resulting in changes in the direction of the waves (the effects are most pronounced at sunrise and sunset).

Just before, and since the war began, intensive research on radio-direction finding continued, and in 1941 the veil was partly lifted on the result of this research—**radio-location.** It is obvious that whilst hostilities continue little can be said in this book even about the lines which research was indicating in the *immediate* pre-war days, but we can at least mention that in its newest form it depends on the *reflection* of electromagnetic waves when they strike a solid body, *i.e.* it does not depend on any emission from the object to be located. The waves which are doing the "finding" are under our own control.

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X'S, *see* Atmospherics

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